



**RANGE SAFETY GROUP**

**SUPPLEMENT TO  
DOCUMENT 323-99**

## **RANGE SAFETY CRITERIA FOR UNMANNED AIR VEHICLES**

### **RATIONALE AND METHODOLOGY SUPPLEMENT**

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**RANGE SAFETY GROUP  
RANGE COMMANDERS COUNCIL**

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## FOREWARD

This supplement describes the rationale and methodology supporting the risk management criteria defined in RCC 323-99 *Range Safety Criteria for Unmanned Air Vehicles*. It provides amplifying background information, examples, definitions, and alternatives to consider when establishing UAV risk management. The rationale descriptions contained in the supplement are organized to correspond paragraph by paragraph to the criteria document.

Multiple criteria are used to examine flight safety from the perspective to ensure a thorough review. Different viewpoints reduce the risk of unrecognized hazards and help to quickly identify and isolate deficiencies. The criteria are used to break up the "safe to fly?" question into a series of presuppositions:

- a. Are system hazards recognized and risk controls available?
  - 1. Risk management criteria
- b. How is this range vulnerable to these identified system hazards?
  - 2. Casualty expectation criteria
  - 3. Property damage criteria
  - 4. Midair collision avoidance criteria
- c. If safeguards are needed to reduce risk, will they work?
  - 5. Adequacy of safeguards criteria

This supplement is based on guidance from safety specialists, existing reference standards and policies, and established procedures from ranges that routinely support UAV operations.

Final authority to conduct a test or operation on a range rests with the Range Commander or his or her designated representative. RCC 323-99 provides definitive criteria for making this risk decision. Definitive criteria which has been reviewed and approved by the Range Commanders Council provides a standard by which the Range Commanders actions can be compared to best practice and to what a reasonable person would do in similar circumstances.

The technology and performance limits of unmanned air vehicles continue to progress at a rapid pace; the corresponding range safety methods, standards, and procedures must keep up with these changes. This supplement describes best practices and procedures known at the time of its publication. The supplement is considered a living document and will be updated regularly.

Change recommendations are encouraged and appreciated, and should be forwarded to [rcc@wsmr.army.mil](mailto:rcc@wsmr.army.mil).

## ACRONYMS

ADS-B	Automatic Dependent Surveillance - Broadcast
AR	Army Regulation
AFB	Air Force Base
AFI	Air Force Instruction
AFPAM	Air Force Pamphlet
ATC	Air Traffic Control
AWACS	Airborne Warning and Control System
CFR	Code of Federal Regulations
COA	Certificate of Authorization
DB	Decibel
DOD	Department of Defense
DR	Dead Reckoning
EWR	Eastern and Western Test Range
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FMECA	Failure Modes, Effects and Criticality Analysis
FTA	Fault Tree Analysis
FTS	Flight Termination System
GCS	Ground Control Station
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
IEC	International Electrotechnical Committee
IFF	Identification Friend or Foe
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
MARSA	Military Assumes Responsibility for Separation of Aircraft
MRTFB	Master Range Test Facility Base
MRU	Military Radar Unit
MTBF	Mean Time Between Failure
NASA	National Aeronautic and Space Administration
NATO	North Atlantic Treaty Organization
NATOPS	Naval Aviation Training and Operating Procedures Standardization
NOAA	National Oceanographic and Atmospheric Administration
NHB	NASA Handbook
ORM	Operations Risk Management
RCC	Range Commanders Council
RDT&E	Research Development Test and Evaluation
RF	Radio Frequency
RFI	Radio Frequency Interference
RLV	Re-usable Launch Vehicle
ROA	Remotely Operated Aircraft
RPV	Remotely Piloted Vehicle

SATCOM	Satellite Communications
SOP	Standard Operating Procedure
STANAG	Standardization Agreement (NATO)
TCAS	Traffic Alert and Collision Avoidance System
UAV	Unmanned Air Vehicle or Uninhabited Air Vehicle
UHF	Ultra High Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
WFF	Wallops Flight Facility

## GLOSSARY

### Acceptable Risk

1. The portion of identified risk that is allowed to persist without further controls. It is accepted by the appropriate decision-maker (AFPAM 91-214). 2. A predetermined criterion or standard for a maximum risk ceiling which permits the evaluation of cost, national priority interests, and number of tests to be conducted (RCC 321-00).

### Casualty Expectation

Risk to people measured as a function of expected fatalities per flight hour of operation.

### Collective Risk

The total risk to an exposed population; the expected total number of individuals who will be fatalities. Defined as Expected Fatalities. Collective risk is specified as either a per mission or per year value (RCC 321-00).

### Containment

The range safety strategy of ensuring risk is minimized by keeping hazardous operations within hazard areas verified to be clear of vulnerable personnel or property.

### Expected Fatalities

The expected number of individuals who will be fatalities. Used to define Collective Risk. This risk is expressed with the following notation:  $1\text{E-}7 = 10^{-7} = 1$  in ten million (RCC 321-00).

### Exposure

The number of persons or resources affected by a given event, or over time, repeated events. This can be expressed in terms of time, proximity, volume, or repetition. This parameter may be included in the estimation of severity or probability, or included separately (AFPAM 91-214).

### Fail safe

1. A design feature that ensures the system remains safe, or in the event of failure, causes the system to revert to a state that will not cause a mishap (MIL-STD-882D) 2. A method built into flight termination systems that will activate an output upon the loss of power and/or RF signal and/or tone. (RCC-319-99)

### Gambling

Making risk decisions without reasonable or prudent assessment or management of the risks involved (AFPAM 91-214).

**Hazard**

Any real or potential condition that can cause mission degradation, injury, illness, or death to personnel or damage to or loss of equipment or property (AFPAM 91-214).

**Hazard Area**

A geographical or geometric surface area that is susceptible to a hazard from a planned event or unplanned malfunction (RCC 321-00)

**Mishap**

An unplanned event or series of events resulting in death, injury, occupational illness, or damage to or loss of equipment or property (AFPAM 91-214, MIL-STD-882D).

**Probability**

The likelihood that an event will occur (AFPAM 91-214).

**Residual Risk**

The remaining risk that exists after all mitigation techniques have been implemented or exhausted (MIL-STD-882D)

**Risk**

An expression of mishap consequences in terms of probability of an event occurring, the severity of the event and the exposure of personnel or resources to potential loss or harm (AFPAM 91-214).

**Safeguard**

Hardware component, software routine, operator procedure, or some combination intended to mitigate risks.

**Safety Critical**

Any condition, event, operation, process, or item whose proper recognition, control, performance, or tolerance is essential to safe system operation and support (MIL-STD-882D)

**Severity**

The expected consequences of an event in terms of degree of impact on the mission, injury, or damage (AFPAM 91-214).

**Waiver**

Granted use or acceptance of an article that does not meet the specified requirement (RCC 319-99)

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## **1. HAZARD RECOGNITION AND RISK REDUCTION CRITERIA**

In RCC Document 323-99, *Range Safety Criteria for Unmanned Air Vehicles*, five separate criteria are used to determine if a UAV is safe to fly on a particular range. The first criteria (risk management) address the question "Are system hazards recognized and risk controls available?"

### **1.0.1 Risk Management.**

Risk management is a process used by decision-makers to handle potentially hazardous operations. The objective of the risk management process is to ensure hazards are identified, evaluated and eliminated or to ensure that the associated risks are reduced to an acceptable level. "Risk Management Criteria," as stated in document 323-99, is a tool that can be used to create or review a UAV risk management program to ensure range safety criteria is met.

### **1.0.2 Why Risk Management is Required.**

**1.0.2.1 References.** Risk management is a requirement of the Department of Defense (DOD) and the National Aeronautics Space Administration (NASA). Use of Operational Risk Management (ORM) (i.e., hazard analysis, risk reduction, and implementation of risk controls) is mandatory throughout DOD. References include OPNAV 3500.39, Air Force Instruction 91-213, and Army AR 385-10. NASA also requires hazard analysis and risk controls for UAV projects. Applicable references include: NHB 1700.1 (V1-B) dated 1993, *NASA Safety Policy and Requirements Document*, and RSM-93, *Range Safety Manual for Goddard Space Flight Center (GSFC)/Wallops Flight Facility (WFF)*.

**1.0.2.2 Approach.** Risk management is a systematic approach performed on the complete system and should be integrated as early as possible because risks are more easily assessed and managed in the planning stages of an operation. Risks may be acceptable, dependent on the probability, severity, and necessity to the successful completion of the mission. With adequate hazard analysis, the range can make informed decisions and apply the appropriate level of restrictions. An inadequate analysis may lead to overly restrictive requirements on the user or unacceptable risk to the range.

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**1.0.3 The Risk Management Program.**

If the user has a risk management program in place, document 323-99, Section 1, "Risk Management Criteria," can be used to validate the approach and the completeness of the program. When the users' risk management program meets these criteria, additional analysis can be avoided, resulting in significant cost and time savings.

If the user's risk management program is not adequate, the criteria can be used to focus on specific problem areas. A checklist of UAV specific hazards is provided to further assist the analyst in determining if anything has been missed. If the user's risk management program is unacceptable or non-existent, the range should require that a risk management program be established. A checklist is provided as a starting point for a UAV program hazard review.

**Note:** The risk management criteria is intended to assess the approach and completeness of the range users' risk management program, not to mandate the format.

Appendix A provides a list of references and information sources that describe general methods to implement a risk management process in range operations. This document will support those risk management processes that are specific to the UAV range test and operations mission. Figure 1.0.3-1 diagrams the concepts of the risk management process that are discussed in the following sections.

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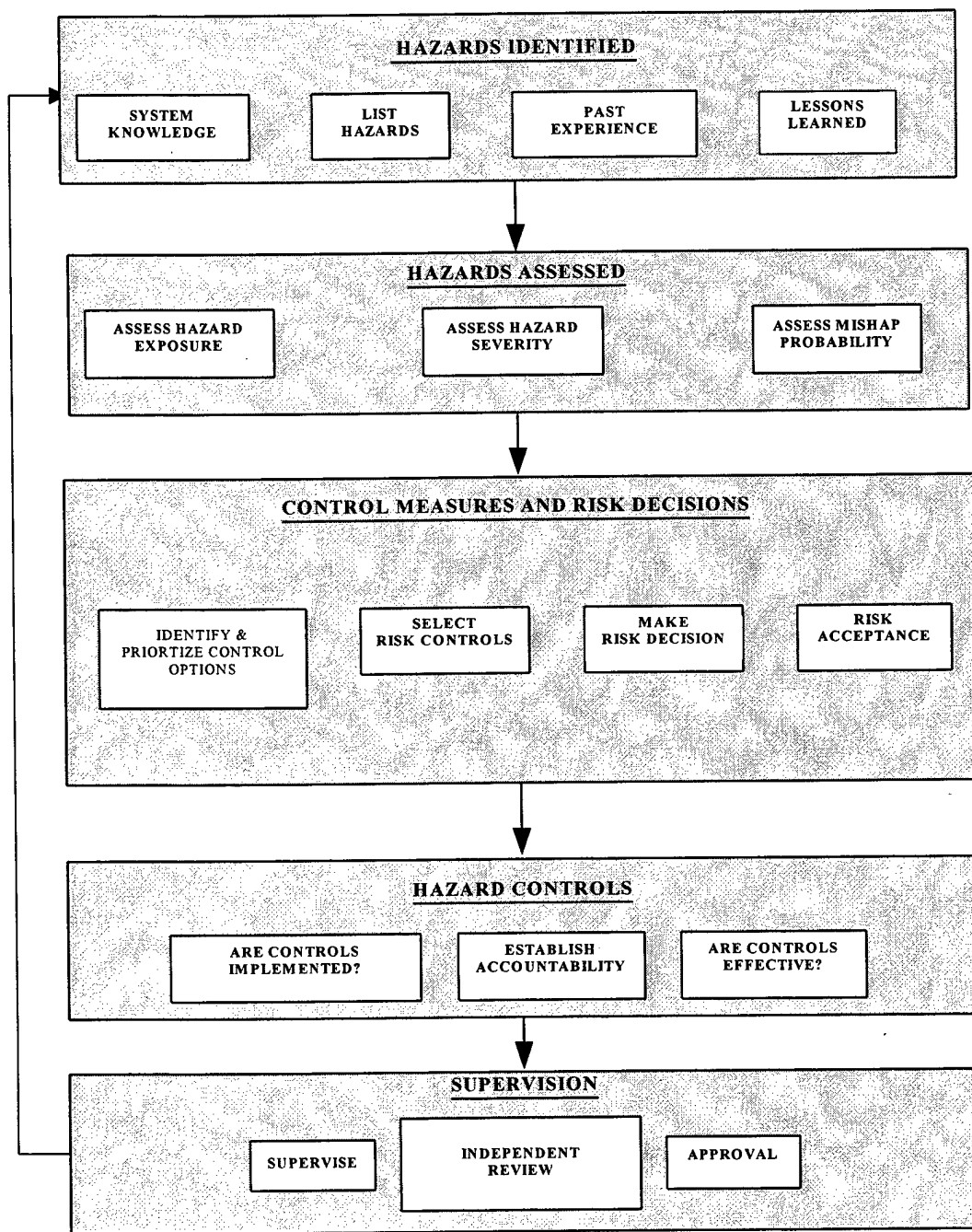


FIGURE 1.0.3-1. The Risk Management Process.

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**1.1 Hazards Identified.** *The hazards associated with the proposed UAV operations have been explicitly stated, based on lessons learned and hazard analysis. Vulnerability to unidentified risk is reduced through hazard analysis efforts.*

Both the range and the user must have a technical and operational understanding of potential UAV system hazards to operate safely. This information also enables safety personnel to identify potential system hazards and review the existing hazard controls. Without explicitly identifying system hazards, the range is vulnerable to hazards that may be present but are not recognized.

Hazards associated with the proposed UAV operation can be identified based on system knowledge, hazard analysis, past experience, and lessons learned. The format used to identify the hazards is not critical, only that the hazards be clearly identified. Examples of documents that may identify hazards include hazard lists, hazard analyses, and user manuals.

Tables 1.1-1 through 1.1-5 list generic hazard conditions and vehicle failure modes which can lead to loss of the UAV, a midair collision, serious injury, and/or death. The background information summarized in these tables is based on mishap data as well as UAV hazard analyses. These tables are generic, not all-inclusive, and may or may not apply to a specific vehicle or situation.

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Table 1.1-1 lists hazardous conditions that may result in loss of control of the UAV, which can ultimately result in an uncontrolled crash or collision.

**TABLE 1.1-1. HAZARDOUS CONDITIONS WHICH MAY RESULT IN  
UNCONTROLLED FLIGHT**

<b>Hazardous condition</b>	<b>Cause</b>
Loss of propulsion	<ul style="list-style-type: none"> <li>• engine failure</li> <li>• fuel starvation</li> <li>• stuck throttle</li> <li>• icing / weather</li> </ul>
Loss of lift	<ul style="list-style-type: none"> <li>• structural failure</li> <li>• icing / weather</li> </ul>
Loss of heading / attitude / position information	<ul style="list-style-type: none"> <li>• heading / attitude system failure</li> <li>• navigation system failure</li> </ul>
Unplanned loss of link	<ul style="list-style-type: none"> <li>• radio frequency interference</li> <li>• flight beyond horizon</li> <li>• antenna masking</li> <li>• loss of ground control station</li> <li>• software interrupt between ground control station and air vehicle</li> <li>• atmospheric attenuation</li> <li>• inadvertent deactivation of autopilot</li> <li>• loss of satellite link</li> </ul>
Loss of control surface performance	<ul style="list-style-type: none"> <li>• stuck servo</li> <li>• autopilot failure</li> <li>• icing / damage to control surface</li> </ul>
Loss of UAV electrical power	<ul style="list-style-type: none"> <li>• generator failure</li> <li>• backup battery failure</li> <li>• excessive load from payload</li> </ul>
Loss of ground control station (GCS)	<ul style="list-style-type: none"> <li>• Loss of GCS power</li> <li>• GCS transmitter/ receiver / antenna failure</li> <li>• GCS computer failure</li> </ul>

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Some mishaps occur when the vehicle impacts the ground even though the vehicle is still capable of controlled flight. This category of mishap is referred to as “controlled flight into terrain.” Hazardous conditions and corresponding causes related to “controlled flight into terrain” are listed in table 1.1-2.

**TABLE 1.1-2. HAZARDOUS CONDITIONS WHICH MAY RESULT IN CONTROLLED FLIGHT INTO TERRAIN**

<b>Hazardous Condition</b>	<b>Cause</b>
Mission planning error or operator error	<ul style="list-style-type: none"> <li>• flight below minimum enroute altitude</li> <li>• undetected man-made obstacles (towers, cables)</li> </ul>
Altitude error	<ul style="list-style-type: none"> <li>• incorrect barometer setting</li> <li>• inadequate alert for altitude deviation</li> </ul>
Navigation error	<ul style="list-style-type: none"> <li>• nav system failure</li> <li>• nav system discrepancy (INS vs. GPS)</li> <li>• map display inaccuracy</li> </ul>
Failure to see and avoid terrain	<ul style="list-style-type: none"> <li>• no capability</li> <li>• autonomous operation</li> </ul>
Loss of link “fly home” mode	<ul style="list-style-type: none"> <li>• mission planning error for loss of link mode</li> </ul>

Table 1.1-3 lists potential hazardous conditions and causes related to a mid-air collision with other aircraft.

**TABLE 1.1-3. HAZARDOUS CONDITIONS WHICH MAY RESULT IN MIDAIR COLLISION**

<b>Hazardous condition</b>	<b>Cause</b>
Navigation error	<ul style="list-style-type: none"> <li>• nav system failure</li> <li>• nav system discrepancy (INS vs. GPS)</li> <li>• map display inaccuracy</li> </ul>
Altitude error	<ul style="list-style-type: none"> <li>• incorrect barometer setting</li> <li>• inadequate alert for altitude deviation</li> </ul>
Unable to “see-and-avoid”	<ul style="list-style-type: none"> <li>• limited capability</li> <li>• autonomous operation</li> </ul>
Mission planning error	<ul style="list-style-type: none"> <li>• inadvertent flight into established routes of other aircraft</li> </ul>
Not seen by other aircraft	<ul style="list-style-type: none"> <li>• strobe / position lights inadequate or fail</li> <li>• IFF failure</li> <li>• TCAS failure</li> <li>• ATC/UAV operator comm link failure</li> </ul>

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Mishaps during takeoff and landing are a significant percentage of all UAV mishaps. Table 1.1-4 lists some hazardous conditions and causes related to this category of mishap.

**TABLE 1.1-4. HAZARDS RESULTING IN TAKEOFF/LANDING MISHAPS**

<b>Hazardous condition</b>	<b>Cause</b>
Pilot induced oscillation	<ul style="list-style-type: none"> <li>• system latency</li> </ul>
Automatic landing system failure	<ul style="list-style-type: none"> <li>• RFI</li> <li>• handoff errors</li> <li>• missed approach procedures</li> </ul>
Operator error	<ul style="list-style-type: none"> <li>• outside weather / wind limits</li> <li>• internal pilot / external pilot handoff errors</li> </ul>

Some factors can contribute to or exacerbate hazardous conditions and increase the chance of a mishap given that a hazardous condition exists. Table 1.1-5 lists some potential contributing factors and their causes.

**TABLE 1.1-5. CONTRIBUTING FACTORS POTENTIALLY RESULTING in VEHICLE LOSS**

<b>Contributing factor</b>	<b>Cause</b>
Inadequate operator response	<ul style="list-style-type: none"> <li>• failure to recognize flight critical situation</li> <li>• flight-critical information missing, erroneous, or ambiguous</li> <li>• delays in information flow</li> </ul>
Incorrect inputs of flight critical parameters	<ul style="list-style-type: none"> <li>• operator entry errors</li> </ul>
Operator information overload	<ul style="list-style-type: none"> <li>• tasking Vs time available</li> <li>• sensory overload over time</li> </ul>
Critical information unavailable, inadequate, blocked, etc.	<ul style="list-style-type: none"> <li>• design dependent</li> </ul>
Latency of flight control commands	<ul style="list-style-type: none"> <li>• operator far removed from control loop</li> <li>• non-deterministic software</li> <li>• control link through satellite</li> </ul>
Operator fatigue	<ul style="list-style-type: none"> <li>• inadequate crew rest</li> <li>• task saturation</li> <li>• long / boring mission</li> </ul>
Control of multiple UAVs	<ul style="list-style-type: none"> <li>• workload issues</li> </ul>
Software paths to unsafe state	<ul style="list-style-type: none"> <li>• unexpected reboot</li> <li>• inadequate software safety process</li> </ul>

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The checklist in Appendix B can also be used to help determine if there are any significant omissions from the range user's risk management program. This list is not intended to be all-inclusive for all UAV, missions/operations, or ranges but is provided as a basic guide or starting point.

**1.2 Hazards Assessed.** *A hazard analysis must be performed and documented. This document shall include the level of risk associated with identified hazards.*

Once hazards are identified they should be expressed in terms of severity and probability of occurrence. This analysis allows the range and range users to focus on hazards which are critical and devote less attention to those that are clearly insignificant. The range may justify accepting some risks without controls if the severity is low, the probability is negligible, or the Range Commander determines the benefits outweigh the costs. If hazards are not assessed in terms of risk (severity and probability), unnecessary requirements may be placed upon the user or the range may accept undue risk.

Severity assessment should be based on the worst credible outcome that can be reasonably expected. For range safety purposes, the severity of the hazard should be determined by its potential impact on people, property, and the environment. Measures of severity for program management can also consider system loss and degradation or mission loss. Severity categories are defined to provide a qualitative measure of the hazards severity. Table 1.2-1 lists common definitions for severity categories.

**TABLE 1.2-1 HAZARD SEVERITY CATEGORIES**

<b>Description</b>	<b>Level</b>	<b>Effect on people</b>	<b>Effect on property</b>	<b>Environmental effects</b>
Catastrophic	I	death, permanent disability	greater than \$1 million	severe
Critical	II	severe injury, permanent partial disability, hospitalization for 5 or more people	\$200,000 to \$1 million	major
Marginal	III	minor injury, 1 or more lost workdays	\$10,000 to \$200,000	minor
Negligible	IV	less than minor injury	less than \$10,000	less than minor

A probability must be assigned to each identified cause of a hazard. A qualitative probability may be assigned early in the mission planning stages and can be combined with the severity category to determine an initial risk assessment. The Risk Assessment Matrix in Figure 1.2-3 may be used to prioritize resources to evaluate and resolve hazards. The following are generally accepted definitions for probability.

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**TABLE 1.2-2. HAZARD PROBABILITY LEVELS**

Description	Level	Incidents per 100,000 flight hours ( note 1)	Individual exposure rate	Fleet or inventory exposure rate
Frequent	A	100 or more	Likely to occur frequently	Continuously experienced
Probable	B	10 to 99	Will occur several times in the life of an item	Will occur frequently
Occasional	C	1 to 9.9	Likely to occur sometime in the life of an item	Will occur several times
Remote	D	0.1 to 0.99	Unlikely but possible to occur in the life of an item	Unlikely but can reasonably be expected to occur
Improbable	E	less than 0.1	So unlikely, it can be assumed occurrence will not be experienced	Unlikely to occur, but possible

Note 1: Probability per flight hour categories from NAVAIRINST 5100.11

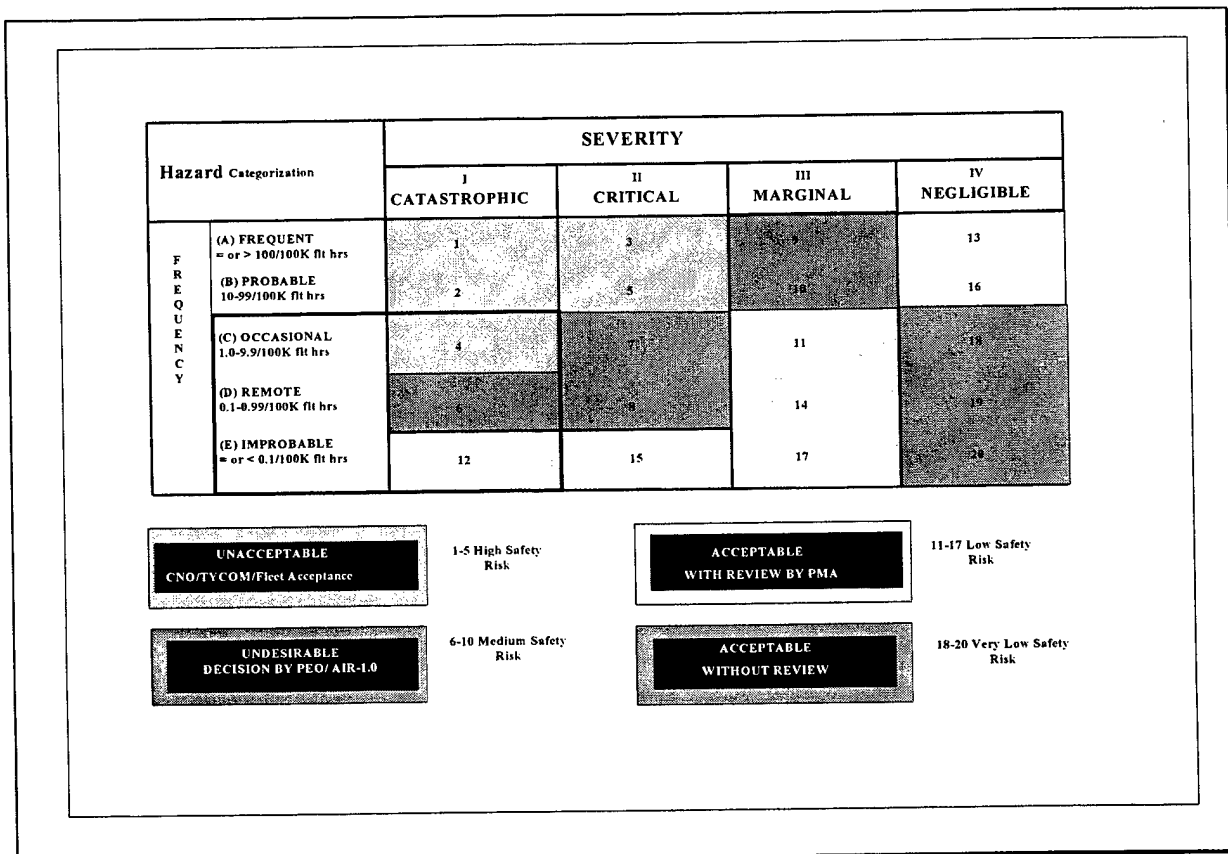


Figure 1.2-3. Risk assessment matrix.

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**1.3 Control Measures and Risk Decisions.** *Control measures to reduce risks to an acceptable level are identified.*

Risks that are unacceptable in terms of severity and/or probability need to be controlled. The user must help identify specific strategies, tools, or safeguards to eliminate or reduce the risk to a level acceptable to the range.

According to MIL-STD-882, the desired order of precedence for implementing control measures is as follows:

- Design for minimum risk. Eliminate the hazard.
- Incorporate safety devices.
- Provide warning devices.
- Develop procedures and training.

**1.3.1 Design for Minimum Risk.**

The best way to control a hazard is to eliminate it by changing the design or adjusting the test and/or training requirements. If the hazard cannot be eliminated, design changes may reduce the risk to an acceptable level. Some examples of design or requirement changes, which may eliminate or reduce risk include:

- Including a highly reliable engine in the UAV design reduces the risk of loss of propulsion.
- Designing a series of tests with a gradual buildup in risk reduces the chance of sudden unexpected catastrophic failure.
- Confining test flights to an unpopulated area eliminates risk to people on the ground.
- Designing a low-level route that avoids populated areas reduces risk of ground casualties from system failures.
- Establishing policy to avoid icing conditions if the vehicle would be at risk in such conditions reduces the risk of icing induced loss of lift or loss of propulsion.

**1.3.2 Incorporate Safety Devices.**

If the hazard can not be eliminated through design change, fixed or automatic safety devices should be incorporated. Provisions for periodic functional checks for these safety devices should be instituted. Examples of safety devices include:

- Back-up battery in case of generator failure
- Redundant communications link in case of failure of the primary link
- Software "fly-home" routine in case of lost link
- Independent flight termination systems

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**1.3.3 Provide Warning Devices.**

If the risk cannot be reduced adequately through design change or use of safety devices, warning devices that detect the hazardous condition and alert personnel of the hazard can be used. Procedures for functional checks of these warning devices should be incorporated. Examples of warning devices are:

- Engine performance safety data displays at the ground control station (i.e., overtemp alert)
- Strobe lights to make the UAV easier to see
- "Low fuel" warning lights
- Warning calls from air traffic control when the vehicle is approaching other traffic or hazard/flight boundaries

**1.3.4 Develop Procedures and Training.**

If it is impractical to eliminate hazards or reduce risk adequately through design changes or safety and warning devices, procedures and training can be used. Safety-critical procedures should be standardized and documented. Tasks and activities that are safety-critical may require certification of personnel proficiency. Examples of safety-related procedures and training include:

- Pre-flight checklists
- Published cautions and warnings
- Emergency procedures
- Specific operating limits
- Established operator qualification procedures
- Requirements for personal protective equipment in specific situations (i.e., hearing protection).

**Note:** Procedures and training should not be used as the only risk reduction methods for high risk hazards.

**1.4 Hazard Controls.** *Control measures used in the hazard analysis are incorporated into range users test plan or procedure document.*

The range user must show that identified control measures are incorporated, understood, and documented. If required, test procedures and monitoring of the control measures must be certified and in place. If the control measures are not implemented, or the implementation is not effective or sufficient, the hazard is still present. If hazards still exist after all control measures are in place, the first step is to re-evaluate the hazard and control measures and verify that nothing was missed and no other solutions are available. Once this process has been established, documentation of all hazards, their respective control measures, and any remaining risks and recommendations must be presented to the appropriate level of authority for a waiver. The

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deciding authority will consider the benefits versus the risks to decide whether a waiver will be granted.

**1.5 Supervision.** *Follow-up evaluations of the control measures are planned in order to ensure effectiveness. Adjustments will be made before continuing with the test or operation.*

Independent review and approval of the documentation, hazard analysis, hazard controls, and test procedures and monitoring must take place prior to the test or operation. This monitoring of safety limits must take place on a continuing basis for each test and/or operation.

**1.6 Alternatives If the Risk Management Criteria Are Not Met.** *If normal risk management criteria are not met, the following alternatives may be exercised.*

- Range may re-evaluate the hazard analysis incorporating changes such as flight parameters, flight path, and new information from the user.
- Range may impose restriction to planned flight to control identified risk.
- Range may require additional control measures or safeguards to control identified risk.
- User can request a waiver from the Range Commander.
- User may not get permission to fly on this range.

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## 2. CASUALTY EXPECTATION CRITERIA

In RCC Document 323-99, five separate criterion are used to determine if a UAV is safe to fly on a particular range. The first criterion, risk management, addresses the question "Are system hazards recognized and risk controls available?" The second criterion, casualty expectation, looks at these potential risks from the perspective of a specific range and the population, which may be exposed to that risk. Casualty expectation is another measure of risk that can provide a basis for a range commander's fly/no fly risk decision. It examines the risk to people on the ground from UAV operations being conducted overhead.

Casualty expectation is defined as the collective risk or total risk to an exposed population; the total number of individuals who will be fatalities. This criterion is met if the hazard is confined to unpopulated areas (see par. 2.1 below) or if the combined vehicle reliability and the population distribution beneath the planned route of flight results in a risk that is no greater than that for manned aircraft operations (see par. 2.2 below).

**2.1 No Risk to Human Life Because Hazard Is Contained.** *The planned route of flight is acceptable, because the flight can be confined to unpopulated areas.*

If the UAV is confined to an unpopulated area, there is no risk of a crash injuring people on the ground. This approach is called "containment." Containment is typically used for flight-testing, high-risk operations, or if the probability of vehicle failure cannot be predicted.

To verify that potential hazards are adequately contained, the safety analyst should verify that the area is unpopulated, and there are adequate control measures on the vehicle to ensure it does not leave the range. Verification that the area is unpopulated is typically done by physically patrolling the range or monitoring it remotely with video. Containment can be also accomplished by erecting a barrier such as a fence.

The safety analyst should also determine if the vehicle is able to leave the range. For instance, is the vehicle's maximum range greater than the distance to the edge of the unpopulated hazard area? Are there failure modes such as "lost link" or "stuck servo" which could result in the UAV leaving a safe area? The safety analyst should review the history of the vehicle or similar designs encountering these failure modes before determining if additional controls are required.

If necessary, an independent or highly reliable system, e.g., Flight Termination System (FTS), may be required to ensure the vehicle does not leave assigned airspace above the unpopulated hazard area. If a "fly home" or "emergency mission" software routine is used to keep the vehicle inside the assigned airspace, the evidence of software reliability must be reviewed. Chapter 5 discusses these review procedures.

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System maturity may or may not support requirements for additional safeguards to keep the UAV inside assigned airspace. A mature system with a history of many mishaps should certainly be treated differently than a mature system with few mishaps.

**2.2 Equivalent Risk to Manned Aircraft.** *A prediction of the average risk to people within the planned area of flight or along the planned route of flight is acceptable, and avoidance of high population density "hot spots" is considered.*

Casualty expectation provides an alternative to containment as a basis for making risk exposure decisions.

RCC Standard 321-00, *Common Risk Criteria for National Test Ranges*, provides the following policy guidance regarding the average risk to people (i.e., casualty expectation) as a risk management alternative to containment:

“As a general policy, safety will be maximized consistent with operational requirements. All ranges strive to achieve complete containment of debris resulting from normal and malfunctioning flights. However, if the planned mission cannot be accomplished under these conditions, a risk management policy may be used if authorized by the Range Commander or his designated representative.”

**2.2.1 Casualty Expectation.** *Must be less than one casualty in a million flight hours.*

One casualty in a million flight hours is a defined risk limit established by the RCC-323 standard. This limit is derived from risks related to manned aircraft as well as system safety precedents. The casualty expectation approach to measuring risk is based on the following premises, which will be amplified in this section:

- Acceptable risk in terms of casualty expectation (fatalities per flight hour) for manned aircraft has been defined within the system safety community.
- There is regulatory precedent that has limited risk exposure from range operations to the risk exposure comparative to overflight of manned aircraft.
- The history of risk exposure to people on the ground from overflight by manned aircraft is measurable in terms of casualty expectation.
- Therefore, defining a risk limit that is consistent with system safety precedents, regulatory precedents, and the history of risk exposure to people on the ground is reasonable.

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**2.2.1.1 System Safety and Casualty Expectation.**

Definitions established within the system safety discipline are consistent with a "one in a million" risk limit for casualty expectation. MIL-STD-882D, *Department of Defense Standard Practice for System Safety*, describes "High Risk" as the probability of a fatality as "occasional" or likely to occur in the life of an aircraft, or likely to occur several times in the entire fleet or inventory of aircraft. "Serious risk" is defined as the probability of a fatality is "remote." "Remote" is defined as unlikely to occur in the life of a specific aircraft, and unlikely but can reasonably be expected to occur in the entire fleet or inventory of aircraft. "Medium risk" is defined as the probability of a fatality is "improbable." "Improbable" is defined as "so unlikely, it can be assumed occurrence may not be experienced during the life of a particular vehicle, and unlikely to occur but possible for a fleet or large inventory of aircraft."

NAVAIRINST 5100.11 further defines risk exposure in terms of flight hours. It defines "occasional" as 1 to 9.9 incidents per 100,000 flight hours, and defines "remote" as 0.1 to 0.99 incidents per 100,000 flight hours. "Improbable" is defined as less than 0.1 mishap per 100,000 flight hours.

**2.2.1.2 Regulatory Precedent.**

Because overflight by manned aircraft occurs on a routine basis, the risk of overflight by manned aircraft is considered "acceptable risk." There is regulatory precedent that has limited risk exposure from range operations to the risk exposure comparative to overflight of manned aircraft. According to RCC Document 321-00, *Common Risk Criteria for National Test Ranges: Inert Debris*, Public Law 81-60 first used this concept in the establishment of the Air Force Eastern Test Range:

"*Public Law (PL) 81-60.* One precedent in U.S. law directly relates to the same hazard as the debris protection standard: in 1949, Congress enacted PL 81-60, *Guided Missiles-Joint Long Range Proving Ground*, which authorized the Secretary of the Air Force to establish a joint proving ground at the present-day Eastern Range location. The law, however, only authorizes the *establishment* of a range. Observations in legislative history delineate to a degree how the location must be chosen.

Contained within the language of legislative history is the requirement for safe operation of the range; "*From a safety standpoint [test flights of missiles] will be no more dangerous than conventional airplanes flying overhead.*" This language was clearly intended to allay public fears at the time missile testing was in its infancy, and was not intended to set future standards."

Even so, this concept is one of the components of Range Safety Policy for both the Air Forces East Coast and West Coast test ranges as described in their Range Safety Manuals (EWR 127-1, *Range Safety Requirement*, 31 Oct 1997, p. 1-11).

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**2.2.1.3 Casualty Expectation from Manned Aircraft.**

The history of risk exposure to people on the ground from overflight by manned aircraft is measurable in terms of casualty expectation. Several sources of mishap rate information show that using 1 mishap per million flight hours is a reasonable number when compared to mishap trends.

Figure 2.2-1 shows yearly ground fatalities per million flight hours for naval aircraft crashes from 1980 to 1998. None of these fatalities were onboard the mishap aircraft. Some of the fatalities were military personnel working near aircraft operations (such as the 1981 carrier deck mishap), but others were not (such as the 1998 Italian cable car mishap). For the 18 years represented, the data shows a mean fatality rate of 1.8 fatalities per million flight hours due to aircraft flying overhead.

**“ Risk of Aircraft Flying Overhead ”**  
**Ground Casualties per Million Flight Hours**  
**US Navy 1980 - 1998**

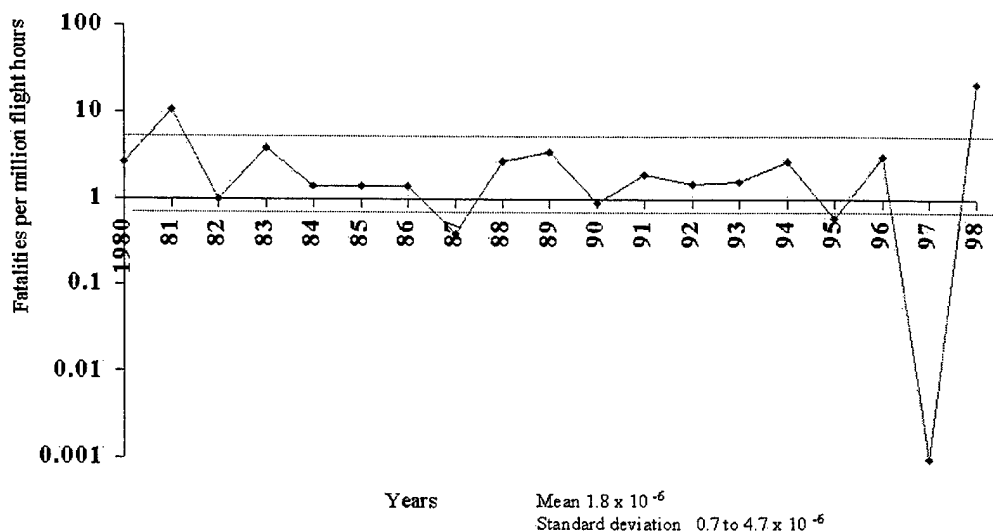


Figure 2.2-1. Ground fatalities for years 1980 –1998.

Figure 2.2-2 compares ground fatalities from Navy, commercial, and general aviation mishaps per million flight hours from 1980 to 1998. The Navy data is identical to the data shown in figure 2.2-1. The commercial and general aviation data is from the National Transportation Safety Board web site. The vertical axis is the mishap rate per million flight hours on a logarithmic scale. The probability boundaries for “occasional,” “remote,” and “improbable” (as

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described in section 2.2.1.1) are shown. The boxes represent the ground fatality rate, plus and minus one standard deviation from the mean, for each category (military aviation, commercial aviation, and general aviation).

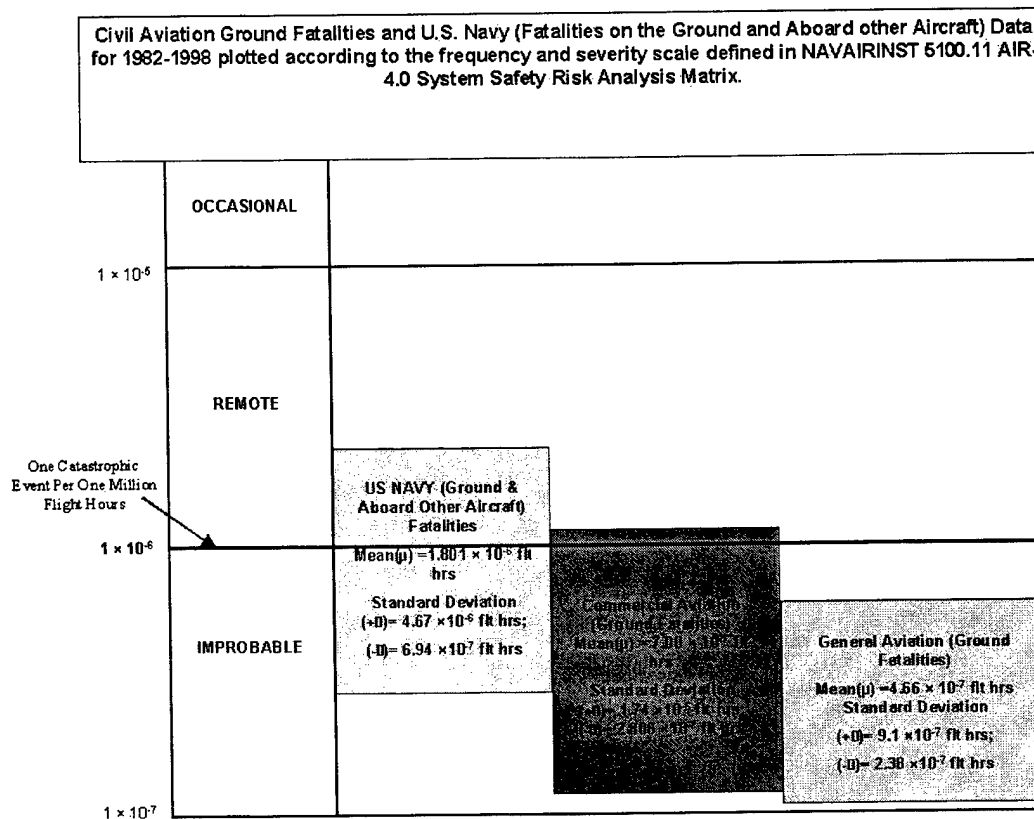


Figure 2.2-2. Mishap trend data.

The mishap trend data shows that using a limit of 1 ground fatality per million flight hours is reasonable, in that is roughly consistent with mishap data.

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**2.2.1.4 Methods of Calculation.**

Casualty expectation is based on UAV reliability predictions or mishap history, crash kinetic energy, vehicle dimensions, flight path, and population along the flight path. Appendix D describes several approaches to calculating casualty expectation.

**2.2.1.5 RCC 321-00 Alternative.**

The Supplement to RCC Document 321-00, *Common Risk Criteria for National Test Ranges: Inert Debris*, provides a detailed approach to calculating casualty expectation. This approach is primarily intended for ballistic missile launches, but can easily be adapted to UAVs in some situations.

**2.2.1.6 Qualitative Alternative.**

When empirical data is not available, this criterion is met if the route is confined to sparsely populated areas and qualitative methods indicate casualty expectation is negligible. Qualitative methods might include these approaches:

- UAV has a lower mishap rate than another UAV of the same size that was previously approved to fly the same route.
- Population density is sparser than required to achieve 1 casualty per million flight hours.
- UAV may be made of extremely light material and unlikely to cause injury.
- People potentially exposed to falling debris are sheltered or briefed on contingency procedures in case of failure.

**2.2.2 Route Selected to Avoid High Population Density Area.** *Routes and altitudes are selected to minimize the possibility of the UAV falling into a congested area in the event of electronic or material malfunction. Route avoids densely populated areas, especially during phases of flight with increased risk.*

**2.2.2.1 Congested Area Considerations.**

The route should avoid areas of high population density such as towns, schools, hospitals, stadiums etc., which would cause the momentary casualty expectation to exceed the acceptable level.

In most cases, population density data can easily be obtained from census data. There may be areas within the census tracts having a higher population density (schools, hospitals, stadiums

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etc.) which are not reflected in the average population density statistic used in the casualty expectation calculation. The resolution size of the census tracts may produce an inaccurate casualty expectation, which may appear to be at an acceptable level. Therefore, consideration of additional criteria may be warranted to avoid these specific sites. Also, DOD and FAA policy guidance directs UAV and aircraft operators to avoid what they refer to as "congested areas."

OPNAVINST 3710.7, *General Naval Training and Operating Procedures Standardization (NATOPS)*, states: "In planning and conducting the flight path to, in, and from operating areas, all activities operating UAVs shall select and adhere to those tracks and altitudes that completely minimize the possibility of UAVs falling into congested areas in the event of electronic or material malfunction." This instruction also requires that operations not create a perception of danger by the public.

This guidance is also consistent with FAA standards. FAR Part 91.119, *Minimum Safe Altitudes*, states: "Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes: (a) Anywhere. An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface. (b) Over congested areas. Over any congested area of a city, town, or settlement, or over any open-air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft. (c) Over other than congested areas. An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In those cases, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure."

#### **2.2.2.2 High Risk Phases of Flight.**

Different phases and types of flight test may have varying levels of risk. It may be acceptable to conduct a low risk operation over a densely populated area with a proven vehicle, but unacceptable over the same area with an unproven vehicle or during phases of flight where there is an increased mishap risk.

Some guidelines for which portions of a UAV flight should be considered "high risk" include:

- Those flights where the probability of a failure is unknown, such as initial flights of a new vehicle
- Portions of a flight where the probability of failure is known to be high enough to result in an "unacceptable" or "undesirable" risk as defined in the risk assessment matrix (previously described in section 1.2).
- Portions of a flight where this UAV or similar types of UAVs have experienced most of their failures. Examples include takeoff and climb-out, and approach and landing and functional check flights.

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- Planned maneuvers intended to explore the edge of the vehicle's performance envelope. Any unusual maneuvers that could lead to structural failure, loss of propulsion, or loss of controlled flight.
- Continued flight after failure of a redundant flight-critical subsystem. For example, after failure of a primary flight system and controlled flight is continuing on a backup system, the operators should consider a contingency plan a "safer" route back to base.

**2.3 Alternatives if Casualty Expectation Criteria Is Not Met.**

- Choose route over less populated areas.
- Evacuate area where casualty expectation is unacceptable.
- Verify the probability of mishap.
- Reduce impact energy (i.e. parachute).
- Investigate the use of an FTS to contain vehicle inside less/non populated areas.
- Investigate Return Home or other recovery mechanism.
- Investigate shelter factor and time of day.
- Request a waiver from the Range Commander.
- Cancel the flight.

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### **3. PROPERTY DAMAGE CRITERIA**

The Property Damage Criteria described in RCC Document 323-99 is an additional consideration in determining whether a UAV is safe to fly on a specific range. The risks associated with a UAV were reviewed by using the "risk management" criteria and the vulnerability of people at a specific range or on a specific route of flight to these risks was previously examined with the "casualty expectation" criteria. This section will look at the vulnerability of property.

Casualty expectation criteria will normally drive "high risk" operations away from centers of high population and their associated properties. Some properties, because of the nature of their function, are located in unpopulated areas. Examples are range assets, hazardous materials storage sites, and culturally or environmentally sensitive sites. The "property damage" criteria ensure that these sites are given appropriate consideration when planning potentially hazardous operations.

Three objectives should always be accomplished when reviewing potential for property damage:

- Determine what properties on the range or near the route of flight are vulnerable.
- Determine what portions of the UAV flight are considered high risk.
- Ensure high-risk portions of the flight avoid vulnerable properties.

**3.1 Identification of High Value/High Consequence Properties.** The facilities or properties that are vulnerable if a UAV crashes should be identified in the safety approval process. In terms of the hazard risk assessment (previously discussed in section 1.2), damage to a facility or property is unacceptable if its damage or destruction could result in one or more of the following severe consequences:

- Loss or degradation of a major function
- Significant monetary loss
- Significant environmental impact
- Significant cultural impeach

Unacceptable loss of a major function is a subjective term that needs to be examined on a case by case basis. Examples of where loss of function is the most significant consequence might be damage to a satellite farm that is the only link to a national asset weather satellite or damage to weapon storage areas.

Significant monetary loss is defined in MIL-STD-882D for two levels of damage in terms of cost: catastrophic and critical. "Catastrophic" damage is defined as \$1 million or more; "Critical" damage is defined as loss between \$200,000 and \$1 million. MIL-STD-882D also defines catastrophic environmental damage as "irreversible environmental damage which

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violates law or regulation. “ Critical environmental damage is damage that is reversible but causes a violation of law or regulation.

Culturally Sensitive Sites are those properties having value in terms of human experience, such as historical sites, religious sites, monuments, etc. A UAV mishap could effect cultural damage that would adversely impact current and future UAV operations.

Another consideration related to property is recovery of the vehicle. Some ranges have conventional munitions impact areas, which may be contaminated by unexploded ordnance and off limits to personnel. If a UAV should fail over such a site, its recovery would be difficult or impossible.

Ranges that routinely conduct UAV operations provided examples of vulnerable properties that they avoid when conducting some UAV operations. This list is neither exhaustive nor all-inclusive.

**TABLE 3.1-1. VULNERABLE PROPERTY AND DAMAGE SEVERITY RESULTS**

Vulnerable Property	Damage Severity Result
Munitions Testing or Storage Site	<ul style="list-style-type: none"><li>• Catastrophic damage to facility or critical monetary loss.</li><li>• Loss or degradation of a major function.</li></ul>
NOAA Satellite Antenna Farm	<ul style="list-style-type: none"><li>• Loss or degradation of a major function.</li><li>• Catastrophic or critical monetary loss.</li></ul>
Public Park, Monument or Property	<ul style="list-style-type: none"><li>• Significant cultural impact.</li><li>• Significant environmental impact.</li></ul>
Toxic waste storage site	<ul style="list-style-type: none"><li>• Significant environmental impact</li></ul>
Fuel tank farm	<ul style="list-style-type: none"><li>• Initiation of catastrophic or critical monetary loss</li></ul>
Geothermal power plant	<ul style="list-style-type: none"><li>• Catastrophic or critical monetary loss.</li></ul>
Native American Sites/Property	<ul style="list-style-type: none"><li>• Violation of negotiated local operating agreement, adverse impact on ability to conduct future operations</li><li>• Significant cultural impact.</li></ul>

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**3.2 UAV Route Considerations.**

The portions of the flight that are considered “high risk” should be identified prior to route selection so vulnerable properties can be avoided during that portion of flight. Guidelines for determining which portions of the flight should be considered “high risk” are provided in section 2.2.2.2.

**3.3 Alternatives If Property Damage Criteria Is Not Met.**

- Change the route or area of operation to avoid the high consequence property or facility.
- Reduce impact energy so no damage occurs (i.e., deploy a parachute).
- Remove or shelter the vulnerable facility if possible.
- Require use of an FTS to ensure vehicle doesn’t get near vulnerable sites.
- Request a waiver from Range Commander to accept increased risk.
- Cancel the flight.

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#### **4. MIDAIR COLLISION AVOIDANCE CRITERIA**

The Midair Collision Avoidance Criteria described in RCC Document 323-99 is an additional consideration in determining whether a UAV is safe to fly on a specific range. The risks associated with a UAV were reviewed by using the “risk management” criteria. Previously, the vulnerability of people and property at a specific range or on a specific route of flight to these risks was examined using the “casualty expectation” and “property damage” criteria. In this section the vulnerability of other aircraft will be discussed.

Collision is avoided by isolating the UAV from other aircraft or compensating for see-and-avoid capability differences with manned aircraft that increase risk of collision. The consequences of a midair collision with a manned aircraft are significant (high probability of fatalities and high cost property damage). Although flight rules have evolved for manned aircraft to avoid collision, UAVs may or may not be compatible with those rules due to latency, visibility, and direct control issues. Midair collision avoidance criteria focuses attention on an examination of these issues.

##### **4.1 Midair Collision Avoidance Criteria Case 1: Exclusive Use within Restricted Airspace or Warning Area.**

This criteria is met if the UAV is contained inside restricted airspace or a warning area, non-participants are excluded, and participants are adequately briefed. Such precautions are warranted because some UAVs may not be able to see and avoid other aircraft, or that ability may be unproven in initial flights of new vehicles. Isolating an unpredictable or unproven vehicle from other aircraft ensures there is no opportunity for collision.

**4.1.1 UAV Containment.** *Assurance that the UAV can be contained within the restricted or warning area boundaries.*

**Rationale:** The UAV must remain within its assigned restricted airspace or warning area so there is no conflict with non-participant aircraft in other airspace.

The hazard analysis or flight history of the UAV may indicate if there are failure modes that may result in the UAV leaving the restricted or warning area. Consider the following failure modes:

- Loss of navigation information: The vehicle may have limited navigation capability, vulnerability to a single point navigation system failure, or the operator station may be limited in the ability to recognize a navigation system discrepancy. Operation in a backup navigation mode (dead reckoning vs. GPS driven, for example) may lead to significant unrecognized position errors.

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- An inability to set local altimeter, unrecognized altimeter discrepancy, or inadequate operator alert for an altitude deviation may cause the vehicle to leave the assigned altitude limits within the restricted or warning area.
- An inadequate mission planning system or erroneous mission plan may lead to flight outside of established boundaries.
- Loss of lift or loss of thrust can result in the vehicle descending below the assigned altitude or the lower altitude boundary of the restricted area. Non-participant aircraft below the restricted area boundary may be vulnerable.
- Loss of link: Without direct operator control, the UAV may fly outside the restricted airspace. Emergency mission or "fly home" routines should be examined to ensure the vehicle will be contained within the assigned area and altitudes.
- Autopilot failure or electrical power failure: Will the UAV quickly lose control and crash or continue flying until fuel is consumed?

Review of the system maturity of the vehicle, failure modes possible, and history of failures can help to determine if an independent flight termination system is required to keep the vehicle inside assigned airspace. The consideration of vehicle operating limits, local airspace geometry, and the presence or absence of emergency backup systems also help determine if an independent range flight termination system must be mandated to contain the vehicle within assigned airspace.

The safety analyst should verify that Air Traffic Control (ATC) or the local military radar unit (MRU) can monitor vehicle position for containment and communicate with UAV controllers in a timely manner. Some portions of the restricted area or warning area may not be visible to air traffic controllers because of radio frequency horizon effects, geographic shadowing, or other limitations of the monitoring system. The analyst should ensure the flight is restricted to locations that can be monitored. The UAV ground control station may be beyond the communications line of sight of the responsible air traffic control (ATC) or military radar unit (MRU). The safety analyst should ensure both the primary and backup communications links with ATC are effective.

**4.1.2 Exclusion of Other Aircraft.** *Assurance that other aircraft can be kept out of the airspace dedicated to UAV mission use.*

**Rationale:** To reduce risk, non-participants are excluded from the hazardous airspace by defining hazardous airspace boundaries and activating the restricted or warning airspace. Examples of some approaches currently used include:

- Declaring predefined portions of restricted or warning airspace temporarily "exclusive use" for specific altitudes for UAV operation.

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- Declaring predefined portions of restricted or warning airspace temporarily “exclusive use” for flight of multiple aircraft including integrated UAV operation. The Flight Leader is responsible for aircraft separation within this airspace. An example of this approach is the MARSAs (Military assumes responsibility for separation of aircraft) approach used at Nellis AFB.
- Defining “UAV work areas” in local procedures manuals and activating them as needed.
- Defining “UAV transit corridors” in local procedures manuals and activating them as needed.

At most ranges, ATC or MRU should be able to monitor the airspace within and near the restricted or warning area and communicate (directly or through controlling agency) with air traffic that may conflict. Where ATC or MRU monitoring capabilities are limited or do not exist, such as UAV work areas at remote desert ranges, airspace might be controlled through scheduling or standardized local procedures. Some examples include:

- The restricted airspace is remote and, historically, there has been no uncontrolled VFR traffic present.
- The area to be flown in can not be monitored, but all approaches to the area can be monitored.
- Visual observation of the remote area by ground observers in contact with the UAV ground control station can be used for low level operations.

The decision-maker must be informed of potential risk associated with limitations of the ability to monitor and communicate with traffic in the restricted or warning areas.

**4.1.3 Participant Coordination.** *UAV operators ensure that flight crews and ATC (or MRU controllers) understand the operation as well as recognize the limitations of the UAV. A local "standard operating procedure" may address routine operations.*

Flight crews and ATC may not recognize hazards associated with a UAV. The vehicle may make unplanned, unusual, or erratic maneuvers due to normal UAV operation or control failures, loss of link, or system failure. These maneuvers may present an increased risk of collision with such participating aircraft as the "chase" aircraft. Also, the small size or stealthy design may make it difficult for participant aircraft to see the UAV.

A local SOP that addresses operational or RDT&E vehicles may be adequate to ensure flight crews and ATC are prepared to accommodate unusual maneuvers or low visibility. If no local SOP applies or a new vehicle is significantly different from UAVs normal for the area, a

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specific brief of the aircrew and / or ATC brief may be required to prepare them to compensate for unusual maneuvers. In those cases where a UAV is integrated into a flight of multiple participating aircraft and the Flight Leader is responsible for separation of aircraft, the Flight Leader should ensure flight crews and ATC are adequately briefed.

**4.2 Midair Collision Avoidance Criteria Case 2: Shared Use within Restricted Airspace or Warning Areas.** *The UAV will be flown in restricted or warning areas along with other aircraft that may not be participating in the UAV's mission or test event.*

This criteria is met if the UAV is contained inside restricted airspace or a warning area, and differences between UAVs and manned aircraft that increase risk to other aircraft (e.g., see-and-avoid capability deficiencies, response delays, etc.) are accounted for. No additional FAA approval is required for restricted or warning area operations conducted in accordance with FAA Order 7610.4.

**4.2.1 UAV Containment.** *Assurance that UAV can be contained within the restricted or warning area boundaries.*

The considerations and rationale here are identical to what has previously been described in section 4.1.1. The difference here is that the airspace control authority for aircraft within the restricted airspace or warning area will be different than outside. The restricted or warning area ATC or MRU will have limited ability to direct and control non-participant aircraft outside the restricted or warning area if a UAV wanders outside assigned airspace.

**4.2.2 Compensating For See and Avoid Limitations.** *The see-and-avoid limitations of the UAV are recognized and compensated for. For example, onboard cameras may have limitations (field of view, sensitivity) and the size of the UAV may make it difficult for other aircraft to see.*

**Rationale:** The pilot in a manned aircraft has the ability to look out for other aircraft in the vicinity, but the UAV pilot may have limited or no capability to see other aircraft. Use of a "chase" aircraft as the UAV's eyes may improve the capability of the UAV to see other aircraft, but the UAV may be limited in its ability to avoid other aircraft because of time delays in controlling the UAV. Even if the UAV has a camera, the instantaneous field of view may not be adequate peripherally to ensure the complete visual scan coverage necessary to see-and-avoid.

The UAV may be difficult for pilots in other aircraft to see, may be small or stealthy in design, have a low visibility paint scheme, or lack anti-collision lights. If such a vehicle will be flying in a see-and-avoid environment within the restricted area rather than "exclusive use," the safety analyst should review the vehicle's ability to perform the following "see-and-avoid" functions:

- Traffic detection
- Threat recognition
- Collision avoidance decisions

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- Collision avoidance maneuvers

**4.2.2.1 Traffic Detection.**

In a manned aircraft, the pilot's primary means of detecting other airborne objects (in visual meteorological conditions) is visual. Traffic advisory cues are typically available from air traffic control or from onboard devices such as the Traffic Alert and Collision Avoidance System (TCAS).

In a UAV, initial detection of potential traffic might come from a number of sources, which may or may not be adequate. For example:

- The chase aircraft has the same visual detection ability as a manned aircraft but has the additional burden of staying close to the UAV which may or may not be easy to track visually.
- If a camera is on board the UAV does it have the ability to detect vehicles coming from several directions at once, analogous to a pilot's peripheral vision? Does it have an adequate field of view and scan rate to continuously monitor those sectors of the vehicle's flight path to adequately detect potential hazards?
- TCAS information can provide situation awareness information to the UAV pilot's ground control station so the pilot has a notion of what aircraft are in the area and can anticipate potential collision avoidance maneuvers. Is the vehicle and ground station so equipped? Similarly, IFF data repeated to the pilot's Ground Control Station from ATC radar or airborne platforms such as AWACS or an E-2 can provide situation awareness information.
- A UAV completely dependent on air traffic control advisories for detection of conflicting traffic does not constitute the ability to see-and-avoid.

**4.2.2.2 Threat Recognition.**

The pilot of a manned aircraft can visually recognize a potential collision and perform evasive maneuvers to avoid that collision. The threat is recognized if the detected object's relative bearing to the pilot's aircraft does not change, and the object is getting larger. Potential collision threat alerts are also available from ATC and such onboard systems as TCAS. A UAV may not have these same abilities. The safety analyst should review the collision threat recognition capabilities of the UAV and determine if they are adequate for the situation. Several considerations for threat recognition follow:

- Will the operator use video camera inputs? Does camera acquisition depend on external cueing from other detection sources? Given that the camera sees another aircraft, does it have a demonstrated ability to determine if the vehicle is on a

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collision course or not? Is it easy to determine where the camera is pointed relative to the vehicle?

- Will the UAV depend on TCAS for traffic alerts? Will all other vehicles in the restricted airspace be equipped with TCAS?
- A UAV completely dependent on air traffic control advisories for recognition of a potential collision does not constitute the ability to see-and-avoid.

**4.2.2.3 Collision Avoidance Decisions.**

In a manned aircraft, the pilot can quickly decide how best to avoid a collision with a recognized airborne threat by climbing, diving, changing speed, or changing heading. In a UAV, because of differing situation awareness implementations and pilot/vehicle interfaces, there may be delays in deciding how best to avoid a collision and what action to take. For instance, the operator's ability to affect the vehicle may be limited to adjusting and uploading a new flight plan to the UAV.

**4.2.2.4 Collision Avoidance Maneuvers.**

There may be a significant delay in the ability to implement a collision avoidance plan once the operator decides what to do. In a manned aircraft, the pilot can quickly and easily manipulate the flight controls. In contrast, the UAV operator may or may not have immediate access to the flight controls affecting speed, heading, and climb or descent. The operator may only be able to upload a new flight plan or execute a few canned avoidance maneuvers.

Vehicles such as Predator with a pilot-in-the-loop will be easier to make quick course, speed, or altitude changes to get out of the way than will vehicles that don't have a pilot directly flying or are primarily autonomous. Also, some vehicles may be extremely slow and cumbersome and relatively less able to make nimble collision avoidance maneuvers. In such cases, the safety analyst needs to determine if there will be significant delays in moving the aircraft and ensure adequate precautions are made.

**4.2.2.5 Collision Avoidance Time Delays.**

Obviously, a UAV operator must be able to recognize a potential collision and maneuver out of the way before the other aircraft arrives. The relative potential closing speeds for a given type of airspace and the distance at which a potential collision is recognized determines the maximum time the vehicle operator has to make the decision to maneuver out of the way.

Time to maneuver out of the way varies from situation to situation. Some typical situations result in 20-40 seconds of time between traffic alert and potential collision. For instance, some restricted areas with advisory services may give alerts when aircraft are 5 miles apart. For tactical jets with a relative closing speed of 700-900 Kts, 20-25 seconds of warning time is

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typical. TCAS advisories at 3.3 miles of separation provide 20 seconds of warning time to vehicles with 600 kts of relative closing speed.

According to FAA Advisory Circular 90-48C Pilots' Role in Collision Avoidance, the nominal time delays in Table 4-1 are typical.

**TABLE 4.2.2-1. NOMINAL TIMES FOR COLLISION  
AVOIDANCE TASKS**

<b>Collision avoidance task</b>	<b>seconds</b>
• Pilot sees object	0.1
• Recognize aircraft	1.0
• Become aware of collision	5.0
• Decision to turn left or right	4.0
• Muscular reaction	0.4
• Aircraft lag time	2.0
<b>Total</b>	<b>12.5</b>

The key thought here is that only seconds are available to avoid a collision. A vehicle that measures its see-and-avoid capability in a significantly longer time is not compatible with a see-and-avoid environment.

**4.2.3 Compensating For Delays With ATC Instruction.** *Vehicles with limited or no see-and-avoid capability are dependent on ATC or military radar unit (MRU) for safe separation. Communication and control delays may increase in comparison with those of manned aircraft. Vehicle response must match airspace conditions and requirements.*

**Rationale:** Vehicles with limited or no see-and-avoid capability are dependent on ATC for safe separation. Communication and control delays may be longer than those of manned aircraft may. These delays may decrease or eliminate the ability of the vehicle to respond to ATC direction in a timely manner. If vehicle response does not match airspace conditions and requirements, there is increased risk of collision.

The design of the UAV may include time delays in the downlink of information to the air vehicle controller or in the uplinks of the controller's commands to the vehicle. The time delay in the communications link between ATC and the air vehicle operator can also be an issue. Examples of sources of delays can include:

- An unusual ATC-to-vehicle ground station link - The normal link is UHF or VHF radio direct from aircraft to ATC. The UAV operator may be beyond line of sight of the ATC facility, and may have to depend on a telephone or SATCOM relay rather than radio direct from the aircraft.

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- Non-deterministic software in the vehicle ground station may delay the display of decision information to the operator, or may delay transmission of critical flight commands.
- Human interface with the vehicle: some vehicles may require the operator to type in a new waypoint or flight plan to make a collision avoidance course change.
- Distance in communications link, especially if the command links use satellites.
- UAVs operating "autonomously": There may not be an operator monitoring, or the vehicle may have lost its link to the ground station.

Each of these examples can result in delays in recognizing a potential collision or a delay in sending collision avoidance commands to the UAV.

**4.3 Midair Collision Avoidance Criteria Case 3: UAV Operations In Other Than Restricted and Warning Areas.** *UAV plans to enter National Airspace, other than restricted area or warning area. FAA is responsible for aircraft separation and must authorize and approve the flight.*

This criteria is met with both (1) documentation of FAA approval and (2) review and approval by the accountable government sponsor.

**4.3.1 FAA Approval.** *UAVs that plan to enter the National Airspace System shall conform to FAA regulations and gain approval from the regional FAA representative. A Certificate of Authorization is required.*

**Rationale:** Flights that require special FAA approval are described in FAA Order 7610.4, Special Military Procedures. In general, any UAV flights outside of restricted areas or warning areas will require approval. Users should coordinate early in the planning stages with the local FAA representative to identify the exact requirements.

**Note:** The FAA refers to unmanned air vehicles as "remotely operated aircraft" or ROAs that must comply with Federal Aviation Regulations like other aircraft.

The process (repeated below) for getting FAA approval in the form of a "Certificate of Authorization" is described in FAA Order 7610.4J Change 1, dated 3 July 2000, entitled SPECIAL MILITARY OPERATIONS.

*"ROAs operating outside Restricted Areas and Warning Areas shall comply with the following:*

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*a. At least 60 days prior to the proposed commencement of ROA operations, the proponent shall submit an application for a Certificate of Authorization (COA) to the Air Traffic Division of the appropriate FAA regional office. COA guidance can be found in FAA Handbook 7210.3, Facility Operation and Administration, Part 6, Chapter 18, Waivers, Authorizations, Exemptions, and Flight Restrictions. The following documentation should be included in the request:*

*NOTE - In the event of real-time, short notice, contingency operations, this lead time may be reduced to the absolute minimum necessary to safely accomplish the mission.*

- 1. Detailed description of the intended flight operation including the classification of the airspace to be utilized.*
- 2. ROA physical characteristics.*
- 3. Flight performance characteristics.*
- 4. Method of pilotage and proposed method to avoid other traffic.*
- 5. Coordination procedures.*
- 6. Communications procedures.*
- 7. Route and altitude procedures.*
- 8. Lost link/mission abort procedures.*
- 9. A statement from the DOD proponent that the ROA is 'airworthy'.* “

**4.3.2 DOD/NASA Review.** *Government sponsor (i.e. the DOD or NASA) must also review and approve if there is any DOD or NASA liability. Differences between UAVs and manned aircraft (e.g., see-and-avoid, and response delays) must be accounted for.*

For RDT&E vehicles operating from MRTFB ranges in accordance with DOD Directive 3200.11, the Range Commander has overall responsibility for UAV flight safety. For operational vehicles, the operational unit Commanding Officer has ultimate responsibility for complying with local range regulations while on the range and FAA regulations when outside the range. According to FAA Order 7610.4J Change 1 3 July 2000:

*“The proponent and/or its representatives shall be noted as responsible at all times for collision avoidance maneuvers with nonparticipating aircraft and the safety of persons or property on the surface.”*

**4.3.2.1 UAV Containment.** *Assurance that UAV can be contained within the boundaries of the pre-planned route of flight defined in the flight plan and approved by the FAA.*

**Rationale:** The considerations and rationale here are similar to what has previously been described in sections 4.1.1 and 4.2.1. The difference here is the route may extend for a longer distance from the ground station, and local weather and air traffic information may be more difficult to obtain. There may be less maneuvering room to accommodate a vehicle which may be less predictable than a manned aircraft. The operator must maintain the vehicle within a pre-

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planned route of flight so there is no conflict with other aircraft or other Special Use Airspace (SUA).

The UAV ground control station may be beyond the communications line of sight of the responsible ATC or MRU. Ensure that both the primary and backup communications links are effective for the entire route of flight and any pre-planned emergency routes.

**4.3.2.2 Compensating For See-and-Avoid Limitations.** *The limitations of the UAV are recognized and compensated for. For example, onboard cameras may have limitations (field of view, sensitivity) and the size of the UAV may make it difficult for other aircraft to see.*

**Rationale:** The considerations and rationale here are similar to what has previously been described in sections 4.2.2. This is a key area of concern in the FAA approval process. In FAA Order 7610.4, a see-and-avoid capability with equivalent levels of safety is mandated as follows:

*"Approvals for ROA operations should require the proponent to provide the ROA with a method that provides an equivalent level of safety, comparable to see-and-avoid requirements for manned aircraft.*

*Methods to consider include, but are not limited to radar observation, forward or side looking cameras, electronic detection systems, visual observation from one or more ground sites monitored by patrol or chase aircraft, or a combination thereof."*

This same order also mandates use of anticollision lights, strobe lights, and IFF:

*"c. ROAs shall be equipped with standard aircraft position lights and high intensity strobe lights in accordance with criteria stipulated in 14 CFR, section 23.1401. These lights shall be operated during all phases of flight in order to enhance flight safety.*

*d. ROAs shall be equipped with an altitude encoding transponder that meets the specifications of 14 CFR, section 91.215. The transponder shall be set to operate on a code assigned by air traffic control. Unless the use of a specific, special-use code is authorized, the ROA pilot-in-command shall have the capability to reset the transponder code while the ROA is airborne. If the transponder becomes inoperative, at the discretion of the affected region or air traffic facility, the mission may be canceled and/or recalled."*

**4.3.2.3 Compensating For Delays With ATC Instruction.** *Vehicles with limited or no see-and-avoid capability are dependent on ATC for safe separation. Communication and control delays may increase in comparison with those of manned aircraft. Vehicle response must match airspace conditions and requirements.*

**Rationale:** The considerations and rationale here are identical to what has previously been described in section 4.2.3. The difference here is the FAA requires an "instantaneous" response as described in FAA order 7610.4:

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*"e. Instantaneous two-way radio communication with all affected ATC facilities is required. For limited range, short duration flights, proponents may request relief from radio requirements provided a suitable means of alternate communication is available. Compliance with all ATC clearances is mandatory."*

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## **5. CRITERIA FOR RELIABILITY AND ADEQUACY OF SAFEGUARDS**

There must be evidence to show that key safeguards will mitigate critical or severe risks. Safeguards must be provided if the hazard analysis requires it or if the UAV or test operation does not meet other safety criteria (e.g., casualty expectation, property damage, collision avoidance) without it. Typical systems that may be considered as safeguards include, but are not limited to:

- Emergency remote pilots
- Flight termination systems
- Software "fly home" software routines
- Parachutes

Procedures that are considered safeguards include emergency procedures, checklists that address safety critical systems, and documented warnings and cautions.

### **ALTERNATIVES IF CRITERIA NOT MET:**

The following alternatives apply to hardware, software, and procedural safeguards:

- Restrict operation to avoid specific hazard
- Add an alternative safeguard to address the specific hazard
- Request a waiver from Range Commander to accept increased risk.
- Cancel the flight

Additional guidance is provided below.

**5.1 Hardware Safeguards.** *Evidence must show that the reliability of key hardware safeguards is adequate. The range may require one or more of the following:*

- **Show evidence of a reliability of 0.999 at 95% confidence level in a representative environment.**

**Rationale:** This reliability number (0.999 at 95% confidence) is the overall reliability goal for flight termination systems. The same goal can be used for other than FTS systems for safety critical applications. According to the FTS standard (RCC Standard 319-99) system reliability is demonstrated by:

“(1) Designing the system to be single fault tolerant

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- (2) Performing qualification, acceptance, certification, and pre-mission testing in accordance with the FTS standard
- (3) Maintaining strict quality control practices during fabrication, test, installation, and test.
- (4) Performing a reliability prediction to show 0.999 probability is met. Use 150% of mission time and analysis in accordance with MIL-HDBK-217E Reliability Prediction of Electronic Equipment, using the applicable environmental factor."

Refer to RCC Standard 319-99 Chapter 4; "RPV, Sub Scale and RLV"; Section 4.4.17, Reliability

- FTS subsystems meet the current RCC flight termination standard (i.e., RCC Standard 319-99 or equivalent)

**Rationale:** If the hazard analysis indicates a flight termination system is required, a system that meets the RCC Standard 319-99 requirements should be acceptable at MRTFB ranges.

- The safeguard subsystem meets an established reliability standard for that type of safeguard. (Define as an example the reliability of a typical FTS, which is required by RCC Standard 319-99, or the FAA.)

**Rationale:** If the safeguard is not a flight termination system, but is instead something not covered by RCC-319, the use of an industry standard related to that type of hardware may be appropriate. If the industry standard addresses the environment the system may be exposed to, there is then a basis for making an informed decision on system reliability.

- The system or safeguard has been tested and can be monitored in flight or will be explicitly checked before flight.

**Rationale:** New systems that have no industry standard can be used if the hazards are recognized and attention focused on the testing, pre-flight inspection, and in-flight monitoring of the system.

**5.2 Software Safeguards.** *Evidence must show that the reliability of key software safeguards is adequate. Examples of software safeguards may include "Fly home" or "emergency mission" routines in the event of lost link, and some "emergency remote pilot" components.*

The range user's risk management plan, as described in section 1 of this document, should identify if there are failure modes that are mitigated with software. If there are software functions that address critical hazards, the range safety analyst needs to know that the software function will work when required. The basic questions to be answered are as follows:

- Have all safety critical requirements been identified? Has the UAV been subjected to a software safety program? Have software functions been addressed in the hazard analyses?

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- Have safety critical software requirements identified in the software safety program or hazard analyses been implemented?
- What assurance is there that these implemented requirements will work? Have they been tested? Can these safety critical software functions be tested before flight or monitored in flight?

Detailed guidance on software safety issues can be found in the *Software Safety Handbook*, Joint Software Safety Committee, and in NASA's *Guidebook for Safety Critical Software - Analysis and Development*.

**5.3 Procedural Safeguards.** *Evidence must show procedural safeguards are adequate. Examples of procedural safeguards are emergency procedures, checklists, operator certification, and training.*

- Operator procedures that will be used as a safeguard must be documented.
- Procedures must have been reviewed and approved by the Range Commander or delegated representative.

**Rationale:** When a malfunction occurs, if the operator can respond quickly and accurately, the probability increases that the vehicle can be recovered safely or that damage can be minimized. The implications of specific safety critical failures are best considered beforehand, when system experts can lay out the best choices for the operators. Written procedures also allow the range to verify that procedures are compatible with local conditions. Checklists for specific safety critical procedures help to ensure complicated actions are performed correctly. Training and operator certification helps to ensure safety critical procedures are properly accomplished when required.

## APPENDIX A

### REFERENCES AND INFORMATION SOURCES

#### A.1 RISK MANAGEMENT REFERENCES AND INFORMATION SOURCES

AFI 91-213, *Operational Risk Management Program*

DOD DIRECTIVE 3200.11, *Major Range and Test Facility Base*

MIL-STD-882, *System Safety*

NHB 1700.1 (V1-B), *NASA Safety Policy and Requirements Document*, 1993:  
<http://nodis.hq.nasa.gov/Library/Directives/NASA-WIDE/Procedures/contents.html>

OPNAVINST 3500.39, *Introduction To Operational Risk Management*

For further information on Risk Management:

Army Safety Center: <http://safety.army.mil/home.html>

Army Risk Management Information Center: <http://rmis.army.mil/>

Air Force Safety Center: <http://rmis.saia.af.mil/>

Air Force ORM Pubs:

AFI 91-213, *Operational Risk Management (ORM) Program*

AFPAM 91-214, *Operational Risk Management (ORM) Implementation and Execution*

AFPAM 91-215, *Operational Risk Management (ORM) Guidelines and Tools*:

<http://afftc.edwards.af.mil/pim/afmenu/91series.htm>

NASA Continuous Risk Management:

[http://satc.gsfc.nasa.gov/support/ASM\\_FEB99/crm\\_at\\_nasa.html](http://satc.gsfc.nasa.gov/support/ASM_FEB99/crm_at_nasa.html)

Navy Safety Center/ORM:

<http://www.safetycenter.navy.mil/ORM/orrmmain.htm>

USMC ORM:

<http://www.hqmc.usmc.milhttp://www.hqmc.usmc.mil/safety.nsf/852564750060e4c88525645d006f6979/fd7ddc822da34c0f852564290069ba99?OpenDocument>

## **A.2 CASUALTY EXPECTATION REFERENCES AND INFORMATION SOURCES**

Title 14 Code of Federal Regulations, Federal Aviation Regulations

MIL-STD-882D, *Department of Defense Standard Practice for System Safety*, 10 February 2000

EWB 127-1, *Range Safety Requirements*, 31 Oct 1997, 45th Space Wing, Patrick AFB FL

Public Law 81-60, *Legislative History*, 81st Congress, pg. 1235

NAVAIR Instruction 5100.11, *Research and Engineering Technical Review of Risk Process and Procedures for Processing Grounding Bulletins*

RCC Standard 321-00, *Common Risk Criteria for National Test Ranges: Inert Debris*

### **For further information:**

**Air Force Safety Center:** <http://www-afsc.saia.af.mil/>

**Navy Safety Center/ORM:** <http://www.safetycenter.navy.mil/>

**National Transportation Safety Board:** <http://www.nts.gov/aviation>

**Range Commanders Council:** <http://jcs.mil/RCC>

## **A.3 PROPERTY DAMAGE REFERENCES**

MIL-STD-882D, *Department of Defense Standard Practice for System Safety*, 10 February 2000

## **A.4 COLLISION AVOIDANCE REFERENCES AND INFORMATION SOURCES**

Title 14, Code of Federal Regulations, Federal Aviation Regulations

FAA Order 7110.65M Change 1, 10 August 2000, Air Traffic Control

FAA Order 7610.4J Change 1, 3 July 2000, Special Military Operations

FAA Advisory Circular AC 90-48C, Pilot's Role in Collision Avoidance

For Further Information:

FAA Home Page: <http://www.faa.gov>

FAA Publications Library: <http://www.faa.gov/atpubs/default.htm>

Federal Aviation Regulations: [http://www.faa.gov/avr/AFS/FARS/far\\_idx.htm](http://www.faa.gov/avr/AFS/FARS/far_idx.htm)

TCAS Information:

FAA TCAS and ADSB Web Page: <http://adsb.tc.faa.gov/>

MITRE Inc: <http://www.mitre.org/pubs/showcase/tcas/tcas.html>

## **A.5 SAFEGUARDS REFERENCES AND INFORMATION SOURCES**

NASA-STD-8719.13A, NASA Software Safety Standard:  
[http://satc.gsfc.nasa.gov/assure/nss8719\\_13.html](http://satc.gsfc.nasa.gov/assure/nss8719_13.html)

NASA-GB-1740.13-96, ASA Guidebook for Safety Critical Software Analysis and Development: [http://www.ivv.nasa.gov/SWG/resources/SWG\\_safety.html](http://www.ivv.nasa.gov/SWG/resources/SWG_safety.html)

STANAG 4044, *NATO Standardization Agreement, Safety Design Requirements and Guidelines for Munitions Related Safety Critical Computing Systems*

*Software Safety Handbook*, Joint Software System Safety Committee, December 1999:  
<http://www.nswc.navy.mil/safety>

IEC 1508, *Functional Safety, Safety-Related Systems*, International Electrotechnical Committee

## APPENDIX B: RANGE SAFETY REVIEW QUESTIONS FOR UAV PROJECTS

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## B.1 INTRODUCTION TO REVIEW QUESTIONS

Range Safety is tasked to identify potential hazards on the range and ensure safeguards are put in place to reduce risk to an acceptable level, consistent with existing local policy guidance. If the operational risks of a specific program exceed specified levels even after implementation of reasonable safeguards, a waiver decision is required from the local Range Commander.

This is a "living document" intended as a tool for Range Safety to evaluate new and ongoing UAV test programs. The document will help ensure the local range commander is fully advised and informed of all known risks. It also serves as a consistent approach to UAV program range safety reviews.

This appendix is focused on hazards that may result in the following consequences:

- UAV crashes which may result in death or injury, or damage to property.
- Mid-air collision between UAV and manned aircraft causing death or injury to pilot, or damage to manned aircraft.

Each section provides questions, based on past experience and lessons learned from other programs, which focus on hazards and safeguards as outlined below:

Section B.2: UAV background information

Section B.3: Potential causes of vehicle loss of control that may result in a crash or flight into non-exclusive airspace.

Section B.4: Common safeguards and emergency procedures to prevent an uncontrolled crash off range or mid-air collision.

Section B.5: The midair collision hazard and system interaction with Air Traffic Control.

Successful completion of this review process will result in confidence that:

- Key system vulnerabilities have been identified
- Safeguards have been verified to exist for these system vulnerabilities
- Safeguards are adequate, and
- Deficiencies or inadequacies of the proposed safeguards have been recognized

When the review is completed, the safety analyst will have enough information to clearly tell the project what deficiencies they must fix, to document for the Range Commander the areas of risk, and to recognize the key range safety issues to monitor during the test.

## **B.2 UAV BACKGROUND INFORMATION**

Background information about the UAV system is required to understand the system well enough to make a defensible risk assessment. This background information is used as a starting point for identifying potential system hazards and reviewing existing system safeguards. Items listed below are basic guidelines with potential reference sources that are helpful in satisfying the requirement for understanding the system.

### **B.2.1 Vehicle Description.**

- Users handbook (NATOPS equivalent)
- Physical dimensions
- Weight (empty and max)
- Mission description
- Crew requirements
- Description of command and control system
- List of hazardous material associated with this vehicle

### **B.2.2 Vehicle Performance.**

- Performance charts
- Max altitude
- Max endurance
- Max range
- Range vs. altitude (glide)
- Cruise speed
- Max speed
- Rate of climb, rate of descent

### **B.2.3 Vehicle Safety History and Reliability.**

Mishap history: What is the flight history of this model UAV? How many crashes and failures have occurred? What has been the corrective action to ensure the failures do not occur again?

Any hazard analyses from contractor or system safety?

Is there an estimate for system mean time between failure? How has this MTBF been determined (analysis or actual data)?

What performance or environmental limitations were used to estimate system MTBF? Will the proposed test exceed any of these limitations?

Is there a software safety program for this UAV system? What flight critical components are software controlled? Have software safety analyses been performed?

#### **B.2.4 Operator Qualifications.**

What personnel are involved in the mission and what are their functions? What information do they have to make safety-related decisions?

What is the basis of the qualification of the vehicle operators? How much experience do they have? How recently have they flown this type vehicle?

#### **B.2.5 Hazardous Materials.**

Any hazardous materials onboard (flammable, toxic, energy storage, ordnance)?

Can a crash start a fire?

### **B.3. CAUSES OF "LOSS OF CONTROL"**

Vehicle loss of control can easily result in a mishap. If we can identify any potential causes of "loss of control" that may have been overlooked, safeguards can be applied, or test conditions can be restricted to reduce risk to an acceptable level.

The following questions focus on system vulnerabilities previously experienced, some of which have resulted in mishaps.

#### **B.3.1 Loss of Command Links.**

What happens when command link is lost?

How does vehicle respond if link is never re-established?

How does the vehicle recognize that loss of command link has occurred?

How does the UAV operator in the ground control station recognize loss of command link has occurred?

##### **B.3.1.1 Backup Communications Links.**

Is there a backup command transmitter and receiver?

Does the backup transmitter have the same or more "effective radiated power"?

##### **B.3.1.2 Link Analysis.**

Has RF link analysis been performed to verify both primary and backup transmitters can communicate with the vehicle at the furthest point in its planned operation?

Does link analysis address all RF links?

- Uplinks from primary and backup ground stations
- Secondary uplinks from each ground station
- Downlinks to primary and backup ground stations
- Flight Termination Link

Does link analysis consider RF horizon?

Is maximum range for each link explicitly stated?

Is there at least 12 dB of signal excess in FTS link?

How do you determine if the primary and backup transmitters are radiating specified output power?

How do you determine if the vehicle primary and backup command and control receivers and FTS receivers are operating at specified sensitivity?

Are there any nulls in the command transmitter antenna pattern? Do the operators know where they are?

Are there areas of RF masking due to location of antennas on the UAV relative to their position and to ground station antennas? Are there RF null spots based on orientation of the UAV?

What is the link susceptibility to multipath? What is the system response if multipath is experienced?

#### **B.3.1.3 Radio Frequency Interference (RFI).**

What is the effect of RFI on the command and control system?

Is there a frequency allocation for all RF links?

What frequency does the UAV system operate on and does this cause any interference with any other local systems?

Is the backup command link sufficiently protected from spurious command signals?

#### **B.3.2 Loss of Vehicle Position Information.**

What are the sources of vehicle navigation position information to the UAV operator? Are there redundant sources so the UAV operator can tell if there is a discrepancy?

If the UAV operator loses primary position information, is control also lost?

Does the UAV operator have access to any external sources of position information that could serve as a backup (radar, IFF, binoculars)?

How does the vehicle autopilot respond to loss of primary internal navigation source? Is there a backup? What are the indications in the ground station to the UAV operator?

### **B.3.3 Loss of Flight Reference Data.**

What are the on-board sources of position, attitude, heading, altitude, and airspeed information to the UAV operator and/or autopilot?

How does the vehicle autopilot respond to loss of primary attitude source? Is there a backup? What are the indications to the UAV operator?

How does the vehicle autopilot respond to loss of primary heading source? Is there a backup? What are the indications to the UAV operator?

How does the vehicle autopilot respond to loss of primary altitude source? Is there a backup? What are the indications to the UAV operator?

How does the vehicle autopilot respond to loss of primary airspeed source? Is there a backup? What are the indications to the UAV operator?

### **B.3.4 Unresponsive Flight Controls.**

What will happen if a servo or flight control sticks or becomes unresponsive? How does the autopilot respond? Is there a backup? How quickly will the UAV operator recognize this?

What happens if the throttle is stuck? How will the UAV operator recognize this condition? Is there a recovery procedure?

### **B.3.5 Loss of Propulsion.**

What happens to the vehicle when propulsion stops?

Will sufficient velocity and electrical power remain for "controlled ditch" or "dead stick landing"?

Can the engine be restarted in flight?

Is the propulsion system affected by environmental conditions (temperature, icing, dust, etc.)? What are the limits? Are the limits and failure modes confirmed by test data? Are limits considered in test plan?

How is fuel volume or fuel utilization monitored?

#### **B.3.6 Loss of Electrical Power.**

What happens when primary electrical power is lost?

Is there a separate battery bus? What does battery bus power? Does automatic system load shedding occur if power is reduced? Are there "essential busses" for reduced power operations?

Are all flight essential systems on an essential bus?

Is there a battery power available time limit associated with loss of electrical power? How long? What if the UAV is too far from base to get back before power runs out?

Does FTS activate if battery backup fails (i.e., fails "safe")?

Does FTS operate on an independent battery circuit?

How is backup battery checked prior to takeoff?

Safety backup system battery lifetime is a critical issue. How do you know how much emergency battery power is left? Is battery usage data available on telemetry? Is a battery use log kept?

#### **B.3.7 Ground Control Station.**

What is the source of electrical power for the ground control station? Is there an un-interruptable backup power source?

What happens if electrical power is lost?

Do backup command transmitter and emergency systems have adequate protection from loss of electrical power?

If power to the ground station is lost, does it affect how flight information is calculated? Do all flight parameters get reset to zero?

### **B.4 REVIEW OF COMMON SAFEGUARDS**

Many UAV designs take similar approaches ("return home" modes, FTS, parachutes, etc.) to safeguards in order to reduce the risk associated with loss of control. Some of these approaches

have not always been adequate. This section asks questions related to the adequacy of those approaches to loss of control safeguards, based on previous experience with several UAV designs.

#### **B.4.1 Degraded Modes of Flight.**

What subsystems will fail and cause the UAV not to be able to continue flying?

Loss of which subsystems will cause the flight to be aborted (i.e., precautionary return to base)?

#### **B.4.2 Return Home Modes.**

Does this vehicle have an automatic "return home" feature (also called "reversion mode" or "Preprogrammed Emergency Mission" in some vehicles) in the event of loss of link?

What conditions cause the vehicle to go into "return home" mode?

What does the vehicle do once it arrives at the "return home" point? Will it climb to a specific altitude? Orbit? Can it land itself? What is the timing and sequence of events?

##### **B.4.2.1 Selection of "Return Home" Point.**

Is the selected "return home" point a safe place to bring an uncontrolled vehicle?

Can the "return home" point be any location, or just the takeoff point?

Does flight path to "return home point" from all points in the test flight plan pass over populated areas? Will the vehicle cross any airspace boundaries? Any mountains or towers higher than its altitude?

During "return home" mode, are altitude limits defined (airspace deconfliction question)? Are these altitude limits compatible with the airspace? What happens if the altitude limits are exceeded?

Will the vehicle be high enough and/or close enough to be in line of sight of primary and backup ground stations?

Are there multiple "return home" points?

##### **B.4.2.2 Operator Entry of "Return Home" Mode Position.**

How is the "return home" position entered?

What safeguards prevent erroneous position input?

If the UAV is required to go to an intermediate waypoint before the "return home" point, how is the waypoint entered and how is it verified?

Is there a pre-launch check of the "return home" mode? Can the "return home" mode "fly to" position be corrected or updated in flight?

#### **B.4.2.3 GPS Vs Dead Reckoning (DR) Navigation Source and "Return Home" Mode.**

How does "return home" mode navigate (dead reckoning, inertial nav, radio beacon homing, GPS)?

Is the reversionary mode tied to GPS? What happens if GPS is not being received or GPS jamming tests are being conducted?

Is there a DR (dead reckoning) "return home" mode if GPS or inertial driven navigation is unavailable or degraded?

#### **B.4.2.4 Failure to Regain Control.**

What happens if the UAV operator fails to regain control of the vehicle once it arrives at the "return home" point and climbs to altitude? Is there a time limit? Does a "Fail Safe" event occur? Does it try to land?

#### **B.4.3 Ditching/Dead Stick Landings.**

What situations would cause the UAV operator to perform a forced landing?

##### **B.4.3.1 Pre-planned Ditching Locations.**

Do pre-planned ditching or forced landing locations exist? Can these locations be reached from any point in the planned route of flight?

What is the criteria for the selection of those locations?

How do you know if these locations will be clear of people? Will the locations be in a controlled area or under surveillance?

#### **B.4.4 FLIGHT TERMINATION SYSTEM**

##### **B.4.4.1 FTS Function.**

Is a flight termination system (FTS) installed? What hazards does it address?

What happens if the UAV is below the RF horizon for both FTS transmitter and vehicle command and control links?

What happens when the FTS activates? Shut off propulsion? Tumble or glide? Does it deploy a parachute?

Who has FTS activation command authority? Vehicle operator? Mission commander? Range safety?

How are vehicle termination parameters monitored?

#### **B.4.4.2 FTS Transmitter.**

Where is the FTS transmitter located?

Does FTS coverage equal or exceed the command transmitter coverage? Does the coverage meet or exceed the maximum range the UAV will fly?

#### **B.4.4.3 Flight Termination Criteria.**

What is the criteria for command activation of the FTS? Does the criteria include:

- Loss of all tracking data
- After all other remedial actions have been taken, a vehicle that cannot be contained within the operating area or range
- If during loss of link mode, a vehicle that does not fly to a predetermined "return home" point

Is the FTS activation criteria adequate to ensure a "good" vehicle is not interpreted as "bad," causing inappropriate use of the FTS?

#### **B.4.4.4 FTS Testing and Certification.**

Who certifies the FTS as "flight ready," and what processes are involved in issuing the certification?

Is the flight termination system independent of other vehicle systems? Does it have its own antenna, receiver, signal processing capability, and power supply?

#### **B.4.5 Fail Safe Mode**

Is there a "fail safe" mode that comes into play if FTS command is not received? What conditions cause it to activate? What happens (engine shut off, flight controls to "turn" or "tumble")?

What causes self activation of the flight termination system? Electrical power loss? Loss of flight critical function? Loss of FTS signal?

Is there a specified time delay between what triggers fail safe mode and actions taken to cause the vehicle to stop flying?

#### **B.4.6 Parachute.**

If the UAV has a parachute system, at what altitude will the chute deploy and what is the impact and drift rate?

What is the rate of descent at max weight?

Are there altitude, airspeed, or attitude limits on deploying the parachute?

Does the UAV have a weight-on-gear inhibit for the parachute system? How is it tested and is the status sent back to the ground with telemetry?

Does the engine have to shut off prior to the deployment of the parachute, and what happens if the engine fails to shutdown? Can the propeller cut the parachute shroud line?

### **B.5 QUESTIONS ABOUT "MIDAIR COLLISION" HAZARDS**

#### **B.5.1 Airspace.**

Will test procedures require exclusive airspace? If not, how will risk to other aircraft be minimized?

If shared, is UAV airspace use compatible or incompatible with any type aircraft or type mission?

How will air traffic control occur with a UAV in the same airspace as manned aircraft?

### **B.5.2 UAV Routes.**

Do planned test routes consider locations of published standard approaches and departures?

Does the test plan specify standoff distances from densely populated areas (schools/hospitals/nursing homes)? Are those sites identified?

Are standoffs required for hazardous sites (fuel depots, weapons storage, etc.)?

Does the test plan address standoff distances from small civilian airfields?

Do "return home" mode locations account for standoffs?

### **B.5.3 Collision Avoidance.**

How does the UAV operator "see and avoid" other aircraft that may be nearby (radar, IFF, visual)?

What does the vehicle use to ensure pilots of other aircraft will see it (TCAS, strobes, bright paint scheme)?

#### **B.5.3.1 Chase Aircraft.**

If a chase aircraft is used to help ensure collision avoidance, is adequate standoff distance specified? Can chase pilot maintain continuous surveillance?

What communications provisions are in place between chase pilot, UAV operator, and range safety?

What is the procedure if the chase pilot loses visual contact with the UAV?

### **B.5.4 Interaction with Air Traffic Control.**

Is there an existing UAV / ATC memorandum of agreement?

Will ATC be briefed for this test or series of tests? What is included in the brief?

Is there an explicit communication link between the UAV ground control and ATC? Is there a backup link in case of emergency?

What are ATC procedures if an unauthorized aircraft enters exclusive airspace being used by a UAV?

What are ATC procedures if UAV leaves exclusive airspace? Does ATC monitor for this?

How do civilian airports and civilian aircraft corridors affect airspace use by UAVs?

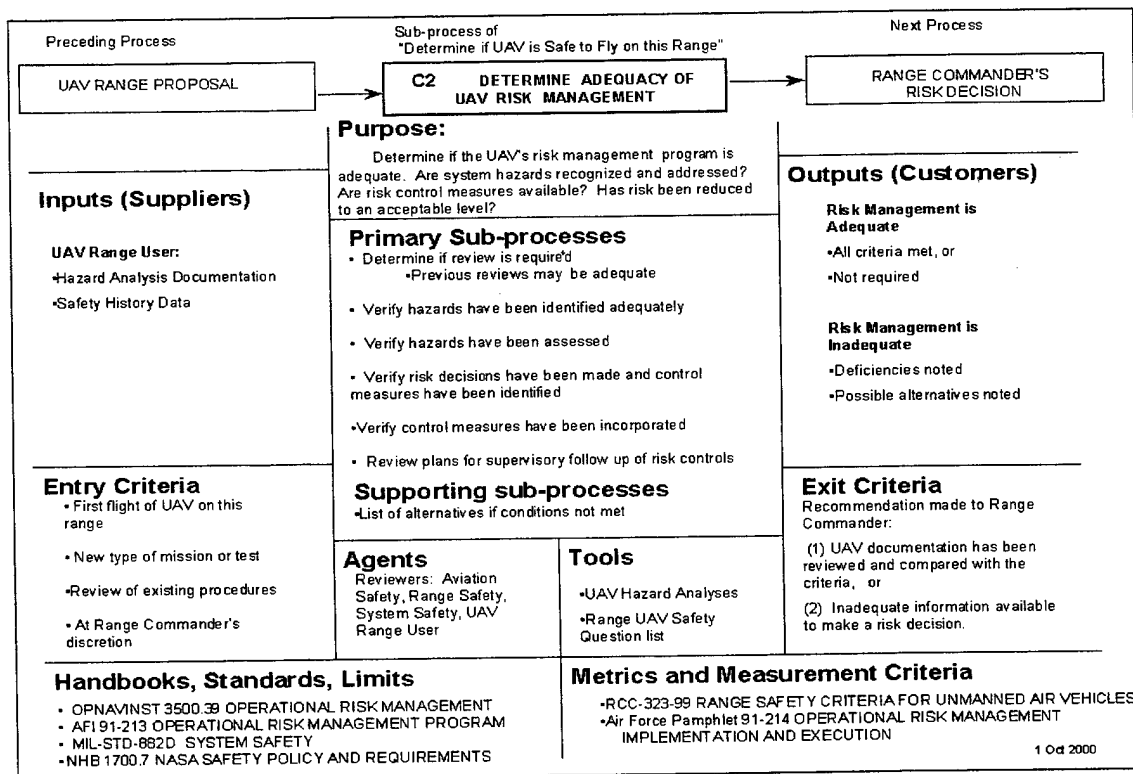
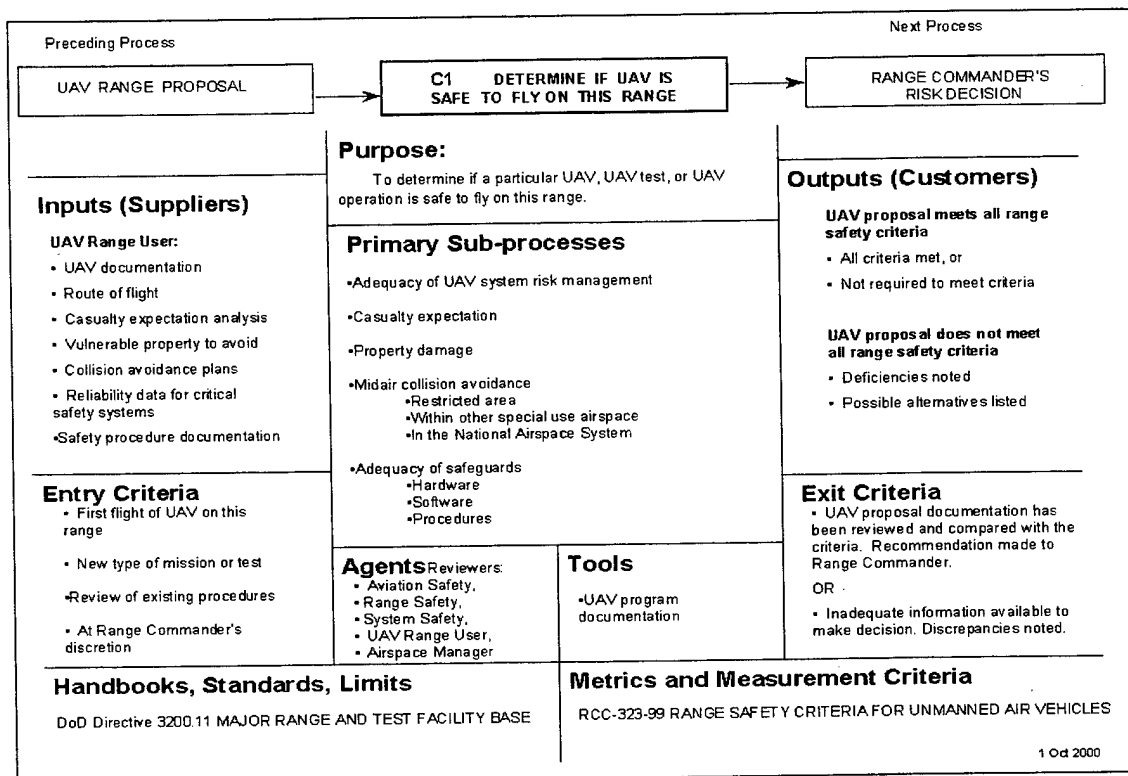
What are the weather minimums for this type vehicle? Can the UAV fly in clouds or IFR conditions?

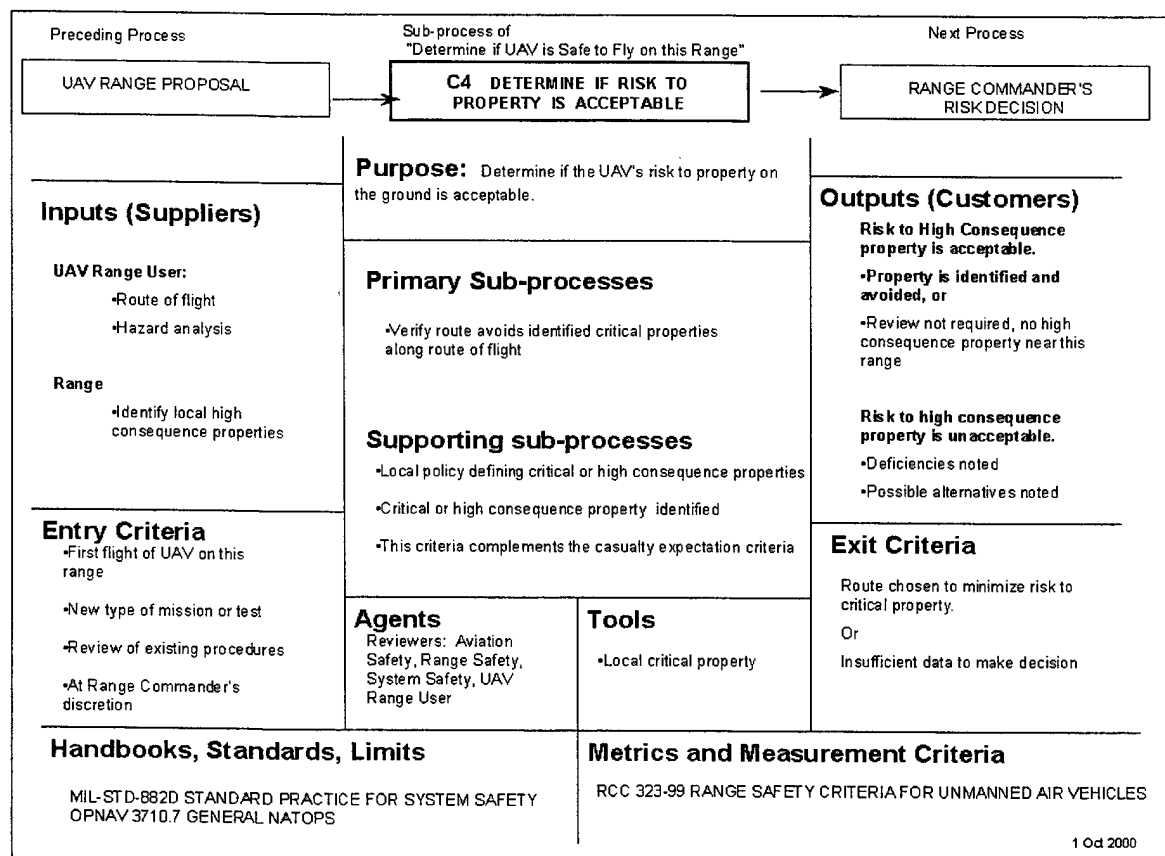
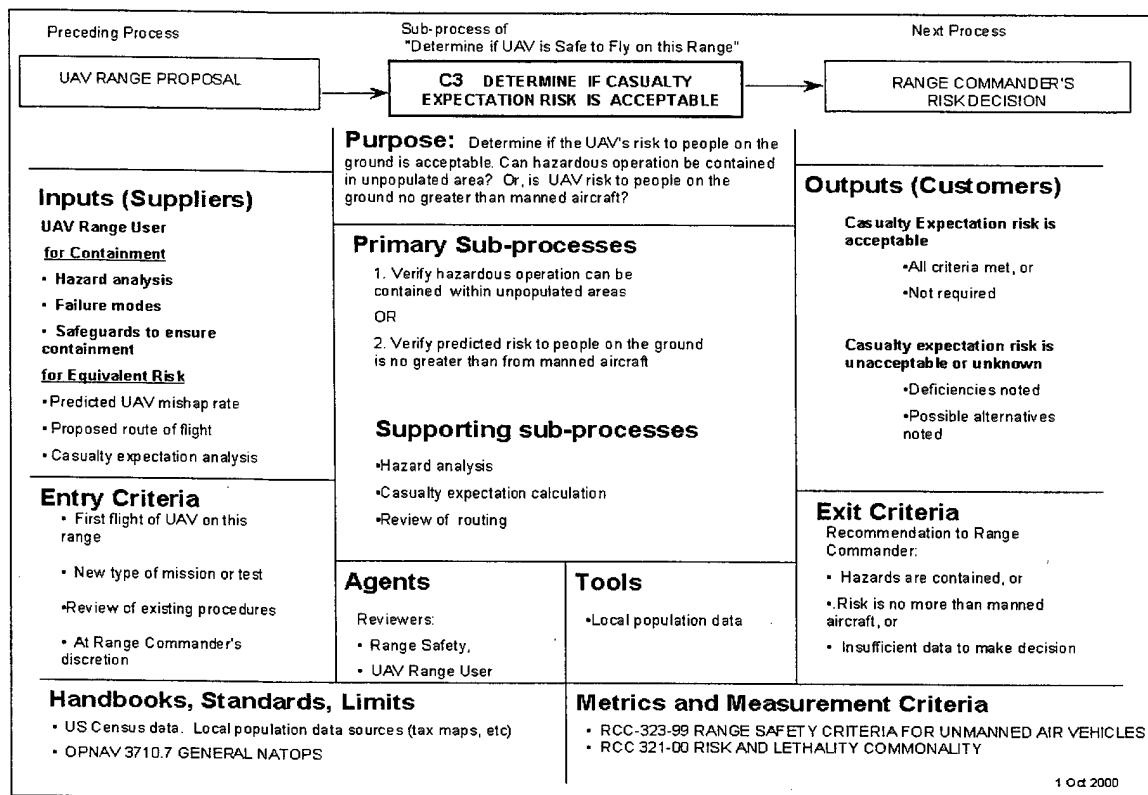
There may already be as much as a 30 second delay for control actions between ATC and manned aircraft. How much will this delay be increased with the operation of this UAV?

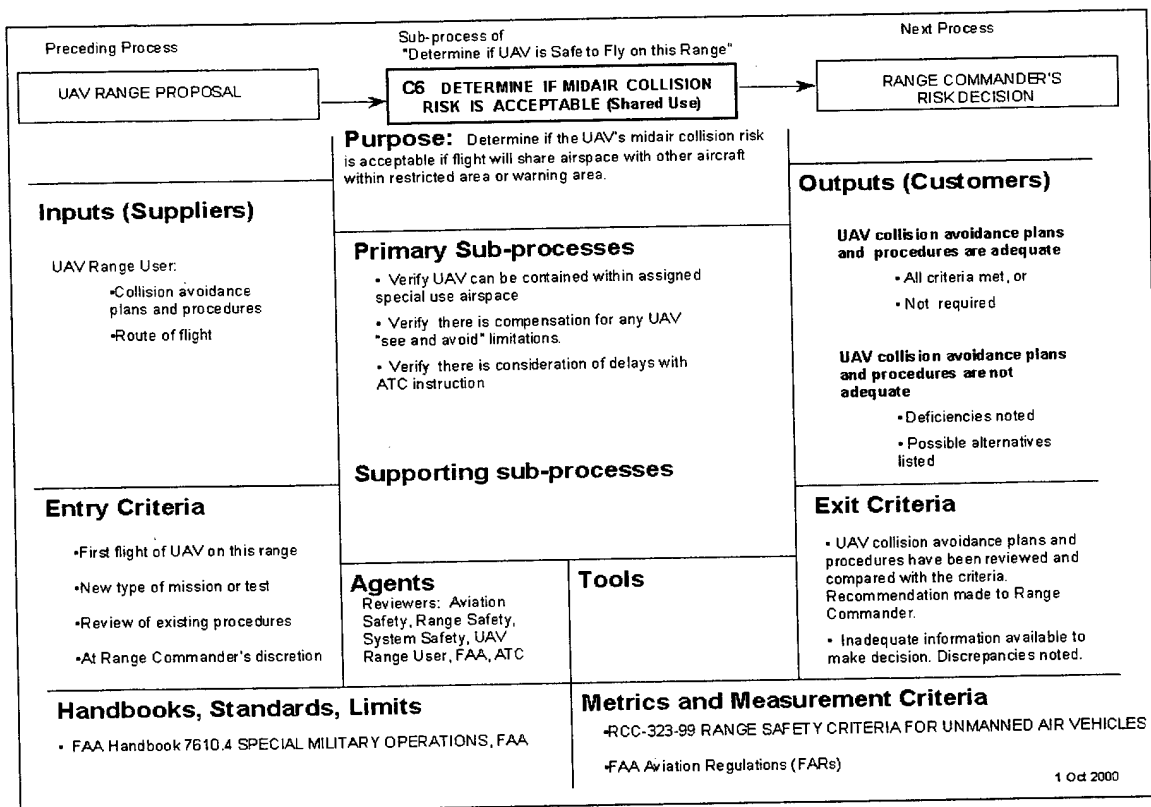
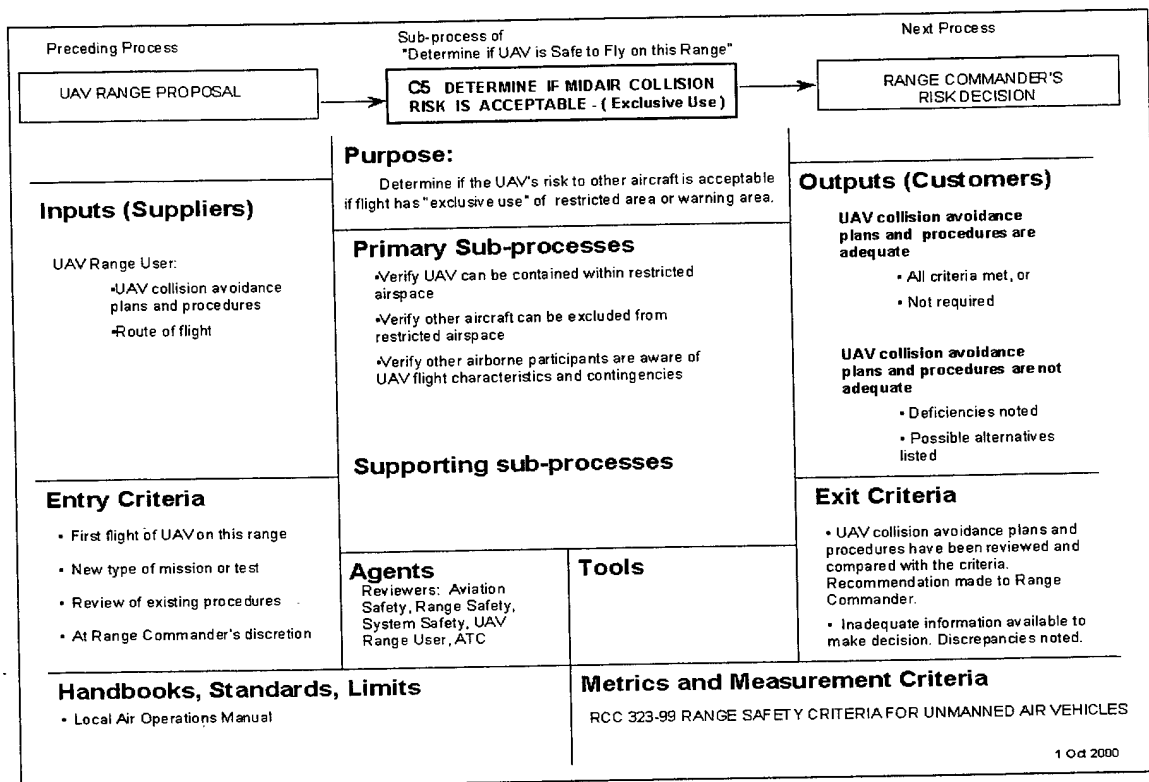
What is the procedure for "loss of IFF"? How will the UAV operator recognize that IFF is not working? Will the UAV return to base or continue its mission?

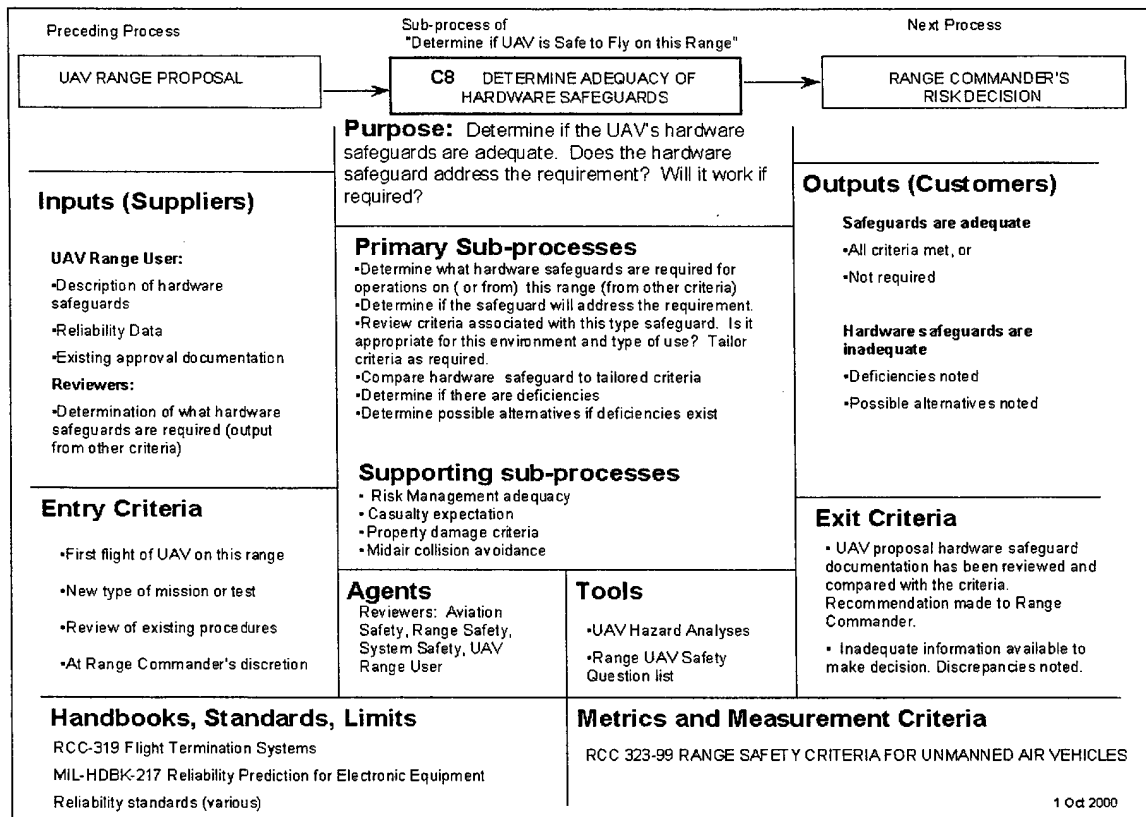
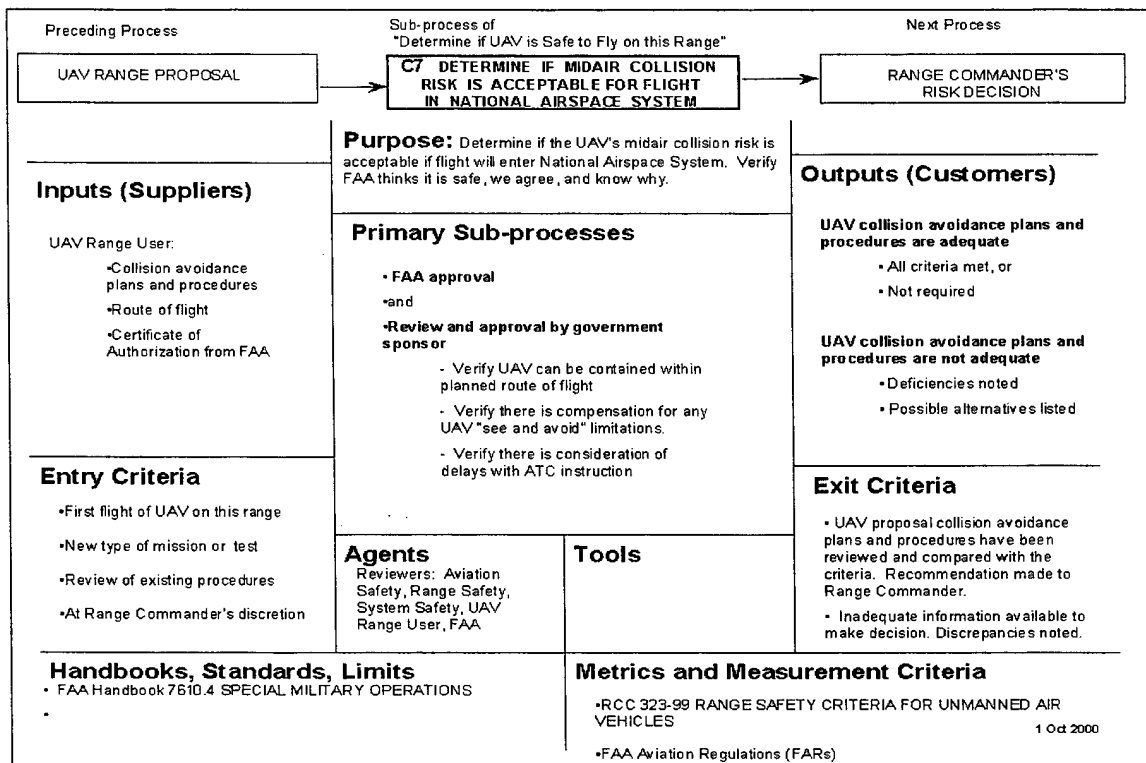
## **APPENDIX C: PROCESS DIAGRAMS**

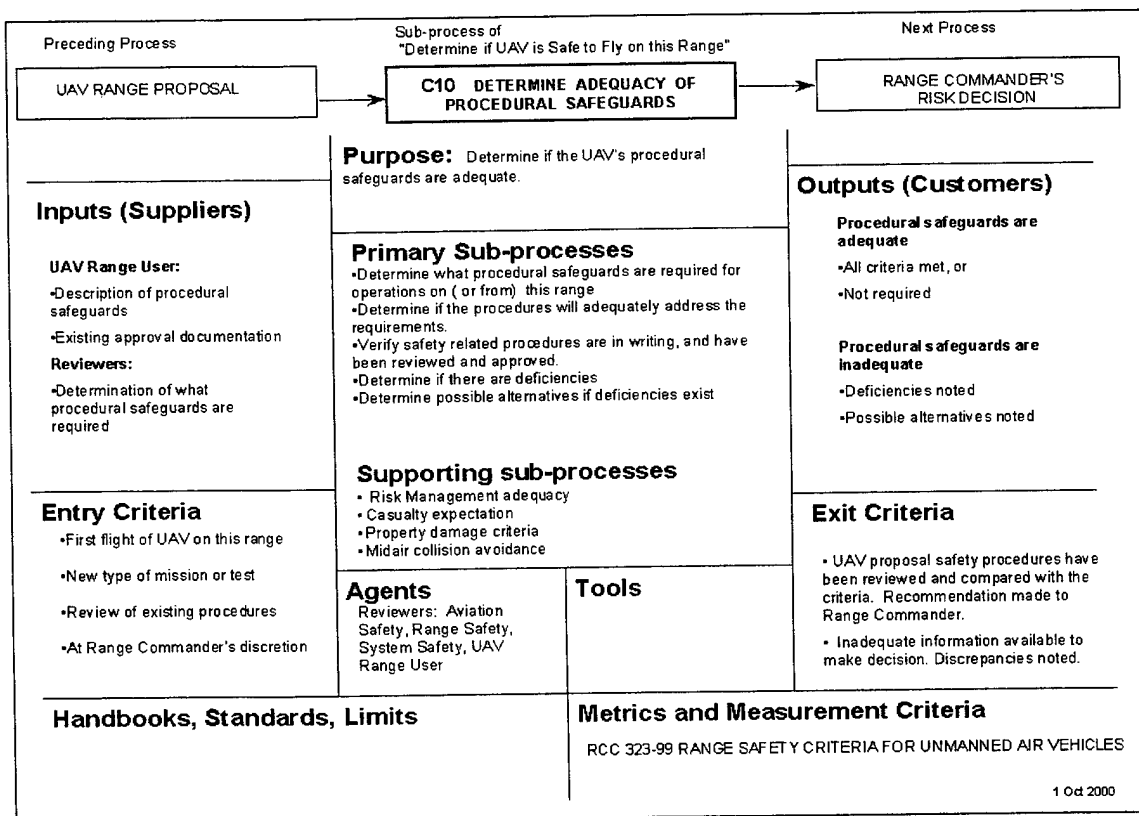
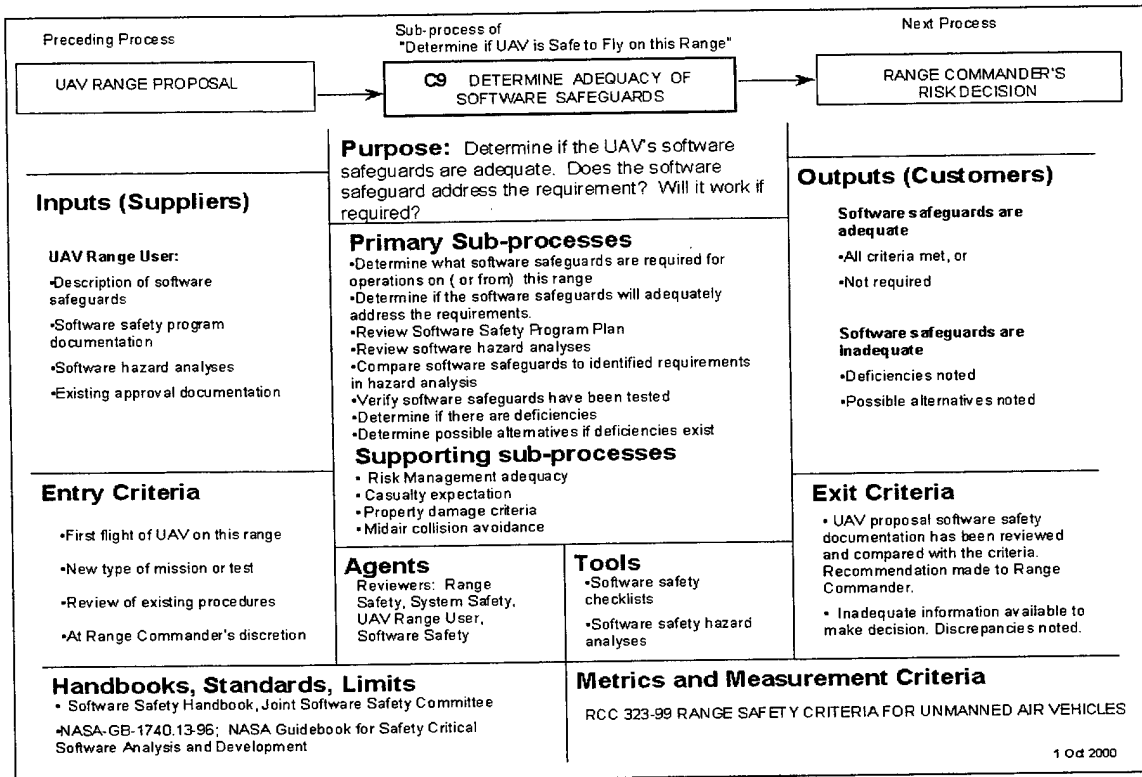
- C1 Determine if the UAV is safe to fly on this range
- C2 Determine adequacy of UAV risk management program
- C3 Determine if casualty expectation risk is acceptable
- C4 Determine if risk to property is acceptable
- C5 Determine if midair collision risk is acceptable (Exclusive Use)
- C6 Determine if midair collision risk is acceptable (Shared Use)
- C7 Determine if midair collision risk is acceptable (National Airspace System)
- C8 Determine adequacy of hardware safeguards
- C9 Determine adequacy of software safeguards
- C10 Determine adequacy of procedural safeguards











## APPENDIX D: CASUALTY EXPECTATION METHODOLOGY

Making an assessment of casualty expectation is not an exact science. The analyst has many factors to consider and there are many of the variables from case to case. The results are valuable because they can help the decision-maker reach a more informed decision on adjusting or approving a particular UAV route or operating area. The following guidelines are provided for the analyst to consider.

### D.1 CALCULATING CASUALTY EXPECTATION

Casualty expectation is defined as the collective or total risk to an exposed population; i.e., the total number of individuals who will be fatalities. This approach to estimating casualty expectation uses the vehicle crash rate, vehicle size, and local population density, and is based on the equation:

$$CE = PF * PD * AL * PK * S \quad (D1-1)$$

where the variable a defined as

**CE** = Casualty Expectation

**PF** = Probably of Failure or Mishap per flight hour

**PD** = Population Density per square mile.

**AL** = Lethal Area

**PK** = Probability of a Fatality given a hit (usually assumed to be 1)

**S** = Shelter factor (if applicable)

The following paragraphs describe procedures for addressing each variable.

Casualty Expectation is a cumulative calculation. Therefore, it must be calculated for each segment of the flight path and summed over the entire flight.

### D.2 PROBABILITY OF FAILURE OR MISHAP

The probability of failure (PF in equation D1-1) or mishap is the expected number of mishaps in a given amount of time (typically flight hours). Several options can be used to determine a mishap rate, based on the type and quality of vehicle history or reliability data available, and accuracy and/or conservatism required. These options include:

- Actual vehicle mishap data
- Estimates based on reliability studies
- Comparison by similarity
- Worst case assumptions
- A combination of these approaches

### **D.2.1 Probability of Failure Based on Mishap Data.**

When available, the actual vehicle failure/mishap rate should be used. This computation requires the most recent year's mishap rate (or average of last 5 years) per 100,000 flight hours and includes the total number of crashes (or failure/mishaps) experienced within this time frame. Mishaps per 100,000 flight hours is the typical measure used for manned aircraft. The average probability of crash can be calculated directly from that number. For example, the Safety Center gives a specific UAV's 5 year history as 700 mishaps in 100,000 flight hours, then the range converts that to  $PF = 0.007$  crashes per flight hour. When using mishap data, the range must consider the following:

- The proposed operation may be more or less dangerous than the type of operation the mishap data is based on.
- The mishap data may be inaccurate. Some UAV programs may not record mishap data or keep an accurate log of flight hours.
- New UAVs may not have accumulated enough flight hours to make an accurate judgment.

If it is a new vehicle, probability of failure data can be estimated by the number of failures encountered as flight hours accumulate.

<u>Hours flown without failure</u>	<u>95% Confidence that <b>PF</b> is equal or less than</u>
10	$3 \times 10^{-1}$
30	$1 \times 10^{-1}$
100	$3 \times 10^{-2}$
300	$1 \times 10^{-2}$

This method assumes:

- Stochastic system behavior
- Exponential failure distribution
- Constant system properties
- Constant environmental stresses

These properties may not be present during initial test flights of a UAV.

### **D.2.2 Probability of Failure Based on Similarity.**

Mishap data from similar vehicles might be considered in estimating probability of failure when adequate data is not available on the actual UAV. An assessment must be made of the differences between the baseline vehicle and the vehicle to be tested, and whether or not these differences significantly affect flight performance or controllability. For example, using Pioneer

mishap data for a Pioneer variant might be valid; but using Pioneer data for a new VTOL UAV would be unacceptable.

### **D.2.3 Estimates From Reliability Studies.**

System safety or reliability assessments based on Fault Tree Analysis (FTA) or Failure Mode, Effects, and Criticality Analysis (FMECA) are basic options for predicting probability of failure when actual data is lacking. Fault trees are useful for analyzing complex components and systems. The FTA is a top-down technique that models failure pathways within a total system. The failures are tracked from a predetermined deficient event or condition to the failure that may be induced. FTAs can be used to identify interrelationships within the vehicle and the support systems, and to identify common cause failures.

On the other hand, FMECA can be used to analyze a system or process to determine how reliable the system and its components are, identify potential failure modes, and determine the effect and criticality of that failure and how these factors can be modified to avoid failures and increase reliability. The FMECA is a bottom-up technique for tabulating each system element that can fail and for assessing the consequences of each failure. The FMECA is described in MIL-STD-1629, *Failure Mode, Effects, and Criticality Analysis (FMECA)*.

### **D.2.4 Worst Case Assumptions.**

In extreme cases where failure/mishap and reliability data or time are not available to perform an in-depth analysis, a "worst case" approach can be examined. If the risk criteria can be satisfied, no further analysis is required. This approach will most likely result in an overly conservative estimate of failure, which may not matter if the UAV flight path is over an unpopulated or sparsely populated area.

Examples of "worst case" assumptions might be:

- The UAV will crash once per flight.
- The UAV will crash once per flight hour.
- The UAV will crash in the most densely populated area

## **D.3 POPULATION DENSITY**

In some cases when dealing with a small controlled area, range personnel counting the number of people or vessels in the area may acquire actual data. In most situations, however, population density can only be obtained through census data or local tax data. While population data is relatively easy to acquire, there are problems associated with such data that must be accounted for. For example:

- Population distributions are not uniform, but the model assumes they are.

- Population data may be out of date. Census data is taken every ten years, and it takes a year or more for it to be published. Therefore, the data must be corrected for annual growth rate, which may be negative in some areas.
- Population may vary with seasons (i.e., beach resorts).

Alternate sources of population data might be locally available. One source may be the local tax district. Local tax maps may identify occupied structures that may be used to estimate population distribution. The local environmental planning office may also have population source data. As with census data, the source, accuracy, and currency of the data must be given appropriate consideration.

#### **D.4 LETHAL AREA**

Lethal area is the area of the piece of concern (there may be multiple pieces if the vehicle breaks up), plus a buffer to account for the size of a person. The analyst may consider the terminal flight path of the UAV when determining lethal area. In some cases, the analyst may assume that the UAV is gliding. Then the lethal area footprint is the swath affected by the wingspan and buffer for the glide distance of the last 6 feet of altitude, plus the distance the vehicle needs to come to a stop.

$$AL = (L + 2B) * (W + 2B) \quad \text{or} \quad AL = (L + DG + DS + 2B) * (W + 2B)$$

L = Length

W = Width

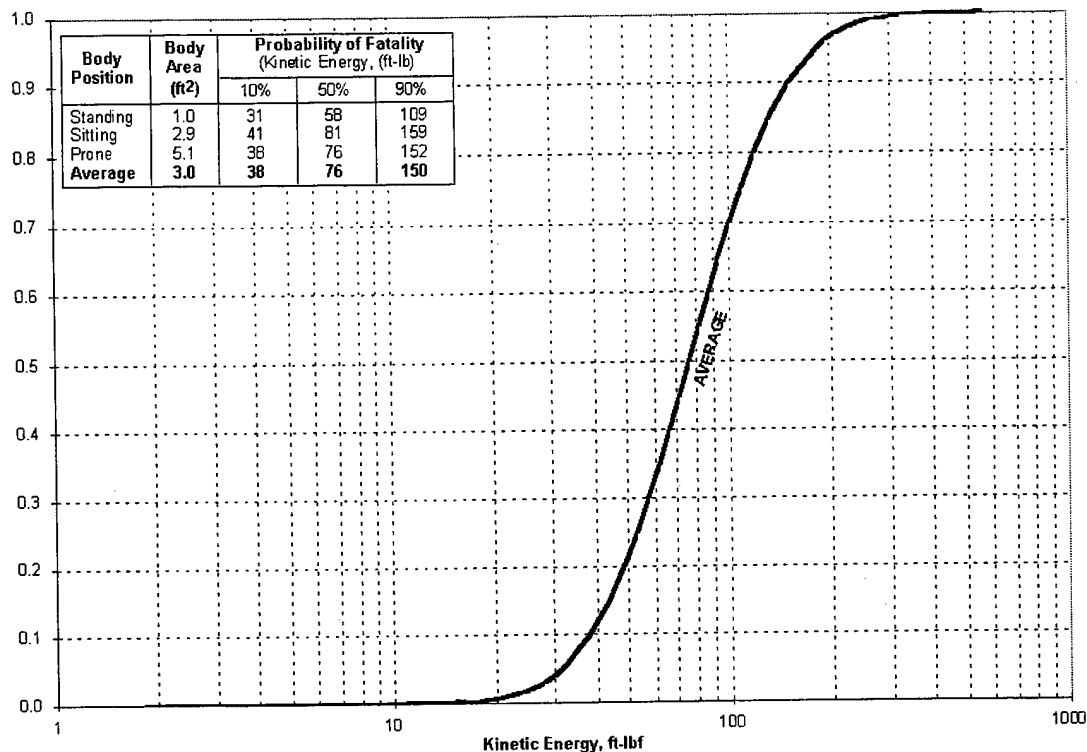
B = Buffer = 1 foot on all sides (commonly used range standard)

DG = Glide distance at 6 ft of altitude

DS = Distance to stop

#### **D.5 PROBABLY OF FATALITY IF HIT**

The probability of fatality depends on the UAV's debris kinetic energy as shown in Figure D5-1, taken from RCC Document 321-00. UAV kinetic energy is estimated using the terminal velocity or VNE (velocity not to exceed) for powered flight, whichever is higher. In most cases, and/or to be conservative, PK is assumed to be 1; that is, any individual hit by a UAV is assumed to be a fatality. Exceptions might be for debris from very light weight material UAVs.



**Figure D.5-1. Probability of fatality from kinetic energy impact.**

The Supplement to RCC Standard 321-00, *Common Risk Criteria for National Test Ranges: Inert Debris*, provides the derivation of this curve

## D.6 SHELTER

The "shelter" factor variable, as used in equation D1-1, is an estimate of how exposed a population is to a vehicle or debris that may be falling. A shelter factor of "1" assumes that the entire population is exposed, and a shelter factor of "0" assumes that the entire population is completely sheltered. The shelter variable is an estimate of the protection houses, cars, and buildings provide and is based on how well those shelters reduce kinetic energy prior to debris impacting people.

Some analysts will use a shelter factor of "1" to be conservative. Others may make assumptions about what percentage of the exposed population is sheltered by buildings, homes, cars, boats, or trees. The Supplement to RCC Standard 321-00, *Common Risk Criteria for National Test Ranges: Inert Debris*, provides guidance on the size and type of debris required to penetrate materials like wood, fiberglass, various metals, and such structures as boats, homes, and commercial buildings.